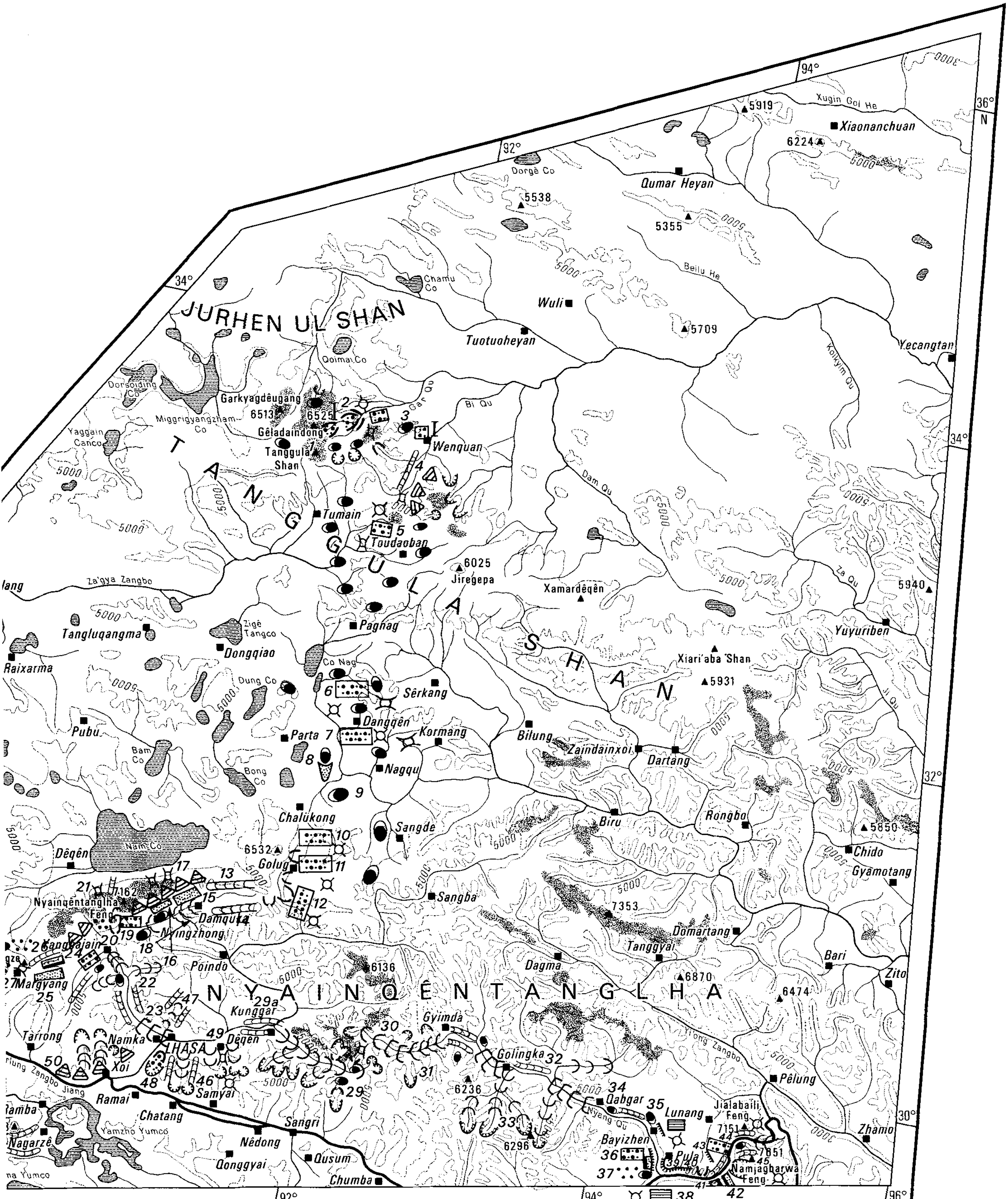
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Quaternary Glaciation of the North Slope of Karakorum Mountains

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ABSTRACT: Three kinds of moraines can be found in the Muztagh valley on the N slope of Mount K2, Karakorum: an old calco-cement moraine lying at the altitude of 5000 m asl, a hilly moraine lying at the altitude of 4200-4800 m asl and a new lateral moraine, lying on both sides of the present river valley. According to the moraines' geomorphology, they are referred to the Middle Pleistocene Glaciation, the Late Pleistocene Glaciation and the Post-Glacial Period respectively.

The lowest level of glacial cirques at 4200-4000 m asl, corresponding to the largest Glaciation, belongs to the Middle Pleistocene (Riss). The ancient cirques at this altitude in the Shaksgam and Yargand valleys are poorly preserved while at the piedmont of the West Kunlun mountains they are represented in better shape. This means that these ancient cirques had been submerged and almost removed by the main ice flow of the valleys. Old cirques, however, are well shaped (or reshaped) where associated with younger cirques at 4600 m asl; they could be considered as the product of the Last Glaciation (Würm). Thus, the equilibrium line altitude (ELA) decreased to 1600 m during the Riss Glaciation and to 1000 m during the Würm Glaciation.

On the basis of the ELA decrease and existence of complex morainic deposits found at the piedmont of the West Kunlun mountains at about 2200 m asl, the author adheres to the opinion that Riss Glaciation had developed an ice cover (ice sheet), with the central ice area located in Karakorum and reaching up to the high peaks of the Kunlun mountains, and down to the piedmont region. During the Last Glaciation an immense ice cap covered the upper parts of the Shaksgam and Yarkant valleys. The paper also deals with the relations between glaciations and tectonic uplift, indicating that topographic and climatic conditions were favourable for the large-scale ice development in the Middle and Late Pleistocene. The uplift may have reached 600-800 m during the Postglacial period. The uplift rates are often reflected by the glaciostatic in the Postglacial Age.

Introduction

Up to now the Quaternary glaciation on the N slope of Karakorum has not been thoroughly studied because of difficult expedition conditions and due to the fact that Quaternary sediment sequences are poorly preserved here as a result of strong tectonic uplift and respective denudation. Karakorum, as a part of the Qinghai-Tibetan plateau, does not have obvious planation surfaces and striking Quaternary sediments. In the main valleys in this area, the Shaksgam and Yarkant valleys, only glacial sediments in the Late Pleistocene and Holocene sediments are found.

Since 1861 foreign scientists went to the region. They described glaciers and related sediments in their reports and books. "There were large wriggling glaciers" (Mason, M. K. 1927, p. 316), and "the existing glaciers in the high mountains of this region could be the largest glaciers of this type, but they are only remnants of even larger glaciers which filled the valley completely during the Ice Age" (Desio, P. A. 1930, p. 409-410). H. von Wissmann (1960) suggested that during the Last Glaciation the boundary of the Shaksgam valley was reaching the altitude of 2940 m and was about 220 km long. Desio (1980), according to the traces of the past glaciation in the confluence of the Muztagh and Shaksgam valleys,

Study area and investigators		Glaciation and corresponding altitude of geomorphic surface				
		Pliocene	Early Pleistocene	Middle Pleistocene	Late Pleistocene	Holocene
Hunza North slope valley	Shi Yafeng (1980) Li Jijun (1983)	Relic planation 5200 m	Shanoz Glaciation 4400–4300 m	Yunz Glaciation 3400–3200 m	Hunza Glaciation 3000–2900 m	Post Glacial 2600 m
Muztagh valley	South slope Desio (1980)			Riss Glaciation 4200–4400 m	Würm Glaciation 3800 m	
Muztagh valley	Wang Zhichao (1983)		Karakorum Glaciation 5100–4900 m	Qogir Glaciation 4670–4400 m	Kaleqing (Shaksgam) Glaciation 4320–4200 m	Post Glacial 3800 m
Muztagh valley	Xu Daoming (1986)	Pliocene planation surface 6000 m	Early Pleistocene broad-valley surface 5400–5200 m	Riss Glaciation 5000–4800 m	Würm Glaciation 4200 m	Post Glacial 3500 m

Tab 1

distinguished two stages of glaciation with the surfaces at 600 m and 160 m above the present valley floor respectively and considered the former to be of Riss age and the latter one of Würm age.

In recent years, Chinese scientists have studied geology, glaciology and geomorphology of this region. Survey and large-scale topographic maps of the region were made as well. Wang Zhichao (1983) studied the Muztagh valley which is tributary of the Shaksgam valley, and divided the Quaternary glaciations into three stages of Early, Middle and Late Pleistocene and compared these to the Quaternary glaciations of the Quinghai-Tibetan plateau.

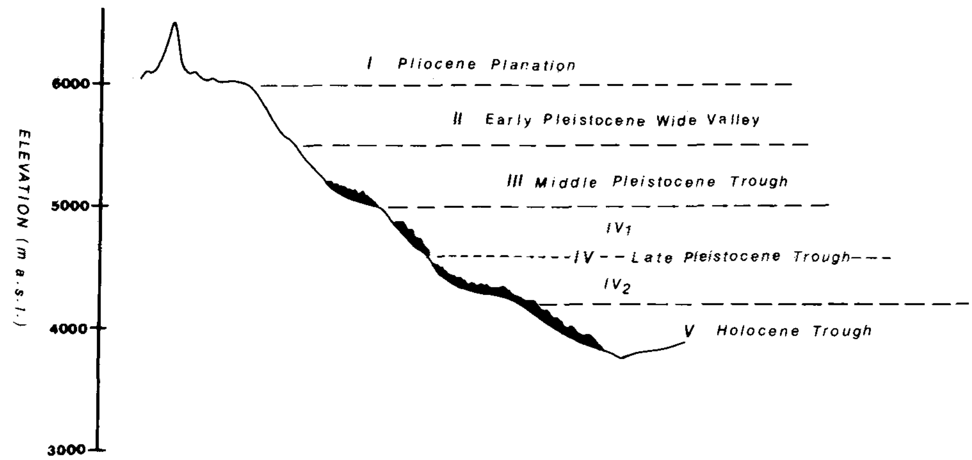
Many good observations of cenozoic geology were obtained from the Indus river valley and Kashmir region of the SW slope of Karakorum. Li Jijun (1983) reviewed the results of the studies of cenozoic geological evolution of these regions, and classified two geomorphic surfaces and the corresponding glaciations in the upper Hunza valley. The highest relic planation surface was located at 5000 m asl representing a Pliocene planation surface. The second surface (4300-4200 m) belongs to the Pleistocene planation (Partudas surface), 1800-2000 m above the present river bed. Shi Yafeng (1980) was the first to find the erratic boulders from the main chain of Karakorum on the Partudas surface and to designate the Shanoz Glaciation. He also classified the Yunz Glaciation of the Middle Pleistocene and the Hunza Glaciation of the Late Pleistocene, and suggested that the glaciation of the Early Pleistocene had characteristics of a semi-covering ice sheet. These results have inspiring significance for the research on the N slope of Karakorum.

Tab 1 compares the Quaternary glaciation of the Hunza valley on the SW slope of Karakorum and the Muztagh valley on the N slope. The altitude of the geomorphic surfaces corresponding to the same glaciations is 1000 m higher on the N slope than on the S slope. On the basis of the landforms and the moraines in particular the author classifies the glaciation of this region and determines the altitudes of planation surfaces at different ages (Fig 1). In contrast to Wang Zhichao, the author suggests that the altitude of the deposits of the Middle Pleistocene glaciation (Qogir Glaciation) is located at 5000 m and thus the Karakorum Glaciation (Early Pleistocene by Wang Zhichao) should be of the Middle Pleistocene age, while the Qogir Glaciation (Middle Pleistocene) changes to an early stage of the Late Pleistocene.

Topographical Features and Tectonic Uplift

When discussing the Quaternary Glaciation on the N slope of Mount K2, we also need to consider the West Kunlun mountains as part of the region. These two mountains belong to two distinct tectonic elements of different geological times. Their border line could be drawn in the centre of the Aghil ranges. Tectonically the West Kunlun mountains represent the Upper Paleozoic fold-upheaval-belt. The age of the magma activity is about 280-240 Ma BP, before the Cretaceous period. Karakorum folded and lifted in the Late Mesozoic. Magmatic intrusions occurred about 79-30 Ma BP. Cretaceous and Tertiary marine facies indicate that the

Fig 1
Schematic geomorphic surfaces and moraine distribution in the northern flank of Karakorum



crust did not rise above the sea level before Late Tertiary. With the Indian Plate (continent) moving northward, the two tectonic elements of different age merged for a common history of the Quaternary Glaciation. The Indian continent, moving northward, twisted the Quinghai-Tibetan plateau into a NW-SE direction and formed a series of feather-like fractions, faults, blocks and small-scale depressions. The basin sediments indicate heavy faulting allover. The neotectonic movement controls the landforms and topography.

The N slope of Mount K2 can roughly be divided into three elements (zones): 1) the Alpine mountain zone which includes the main massives of Karakorum, the Aghil ranges and the West Kunlun mountains. The average crest altitudes are 6500 m asl, 6000 m asl and 5500 m asl respectively and represent the primary planation surface tilted northward; 2) the middle low mountains with an elevation of 4000-3000 m; 3) the loess covered foreland at less than 3000 m extending far northwards to the desert formed of Quaternary sediments from the mountains.

In Karakorum the Shaksgam valley is 2000-3000 m deep and 4000-6000 m wide. The big horns and sharp ridges above the trough shoulder contrast with the broad flat floor of the valley covered with the later alluvium-proluvium fan deposits from both sides. Upstream in the high mountain zone of the present rivers on the N slope of the West Kunlun mountains the valley floor widens up to 10 km. The high mountainous zone is not only affected by the strong uplift but also by heavy Quaternary Glaciation.

The Qinghai-Tibetan plateau has risen to an average height of 5000 m from the Thetys sea of the Pliocene. Li Bingyuan with co-authors (1983, p.118-120), using the zoo- and phytofossils data, estimated the rise of the plateau from approximately 1000 m to 3500-4000 m during the Quaternary. Shi Yafeng et al. (1964) and Li Jijun et al. (1979), when discussing the rise during various periods of the Quaternary, estimated it as 1000 m in Early Pleistocene, another 1000 m in Middle Pleistocene and further 1700 m in Late Pleistocene. Hsü Jen (1981) obtained similar results, and reminds that the post-glacial time of 7000-9000 years represents an additional rise of about 600-900 on the S slope of the Himalayas. These conclusions coincide with the results obtained for the W slope of the plateau. Puris (1964) pollen analysis from the Karewa group indicates an uplift of 2700 m since the Middle Pleistocene. H. de Terra (1939) suggested that the uplift during the Late Pleistocene was stronger. The altitude of the High Himalayas at its W margin averages close to 5000 m. Generally, the uplift culminates in the Himalayas, and the uplift rate of Karakorum is not less. In the study area not only the main boundary faults and the junction between the two continents wedge deeply into Karakorum mountains but also the age of the magmatic intrusions is 4-8,6 Ma (Desio, A. et al. 1972, see Li Jijun et al. 1983), while the age of magmatic intrusions on the N slope of the Himalayas is 10 to 20 Ma. On this basis the author tried to establish the relation between relief and the ice age on the N slope of Mount K2, Karakorum.

The highest surface (Fig 1) is the average elevation of the main ridges, representing the mountain-top planation surface from Karakorum sloping to the West Kunlun. The altitude of the second surface is 5500 m in Karakorum and 5200 m in the West Kunlun. The Aghil range consists of long ridges with low inclination towards the valley or a row of hills with further denudation coming to a narrow rim of a relic platform in the West Kunlun mountains. The third surface is a glacial trough at 5000 m asl in the upper Shaksgam valley and the upper Yarkant valley. The surface is about 6 to 10 km wide, and the surface down from the valley consists of discontinuous terraces and relic platforms. Old calco-cement moraine was found on the terrace surface in the Muztagh valley. The surface is located at 4800 m asl in the West Kunlun, it is a well preserved broad valley surface about 5 to 15 km wide. The fourth surface is a broad U-shaped valley in one or two sections of Karakorum covered with singular moraine hills. In the West Kunlun mountains the surface is a perfectly U-

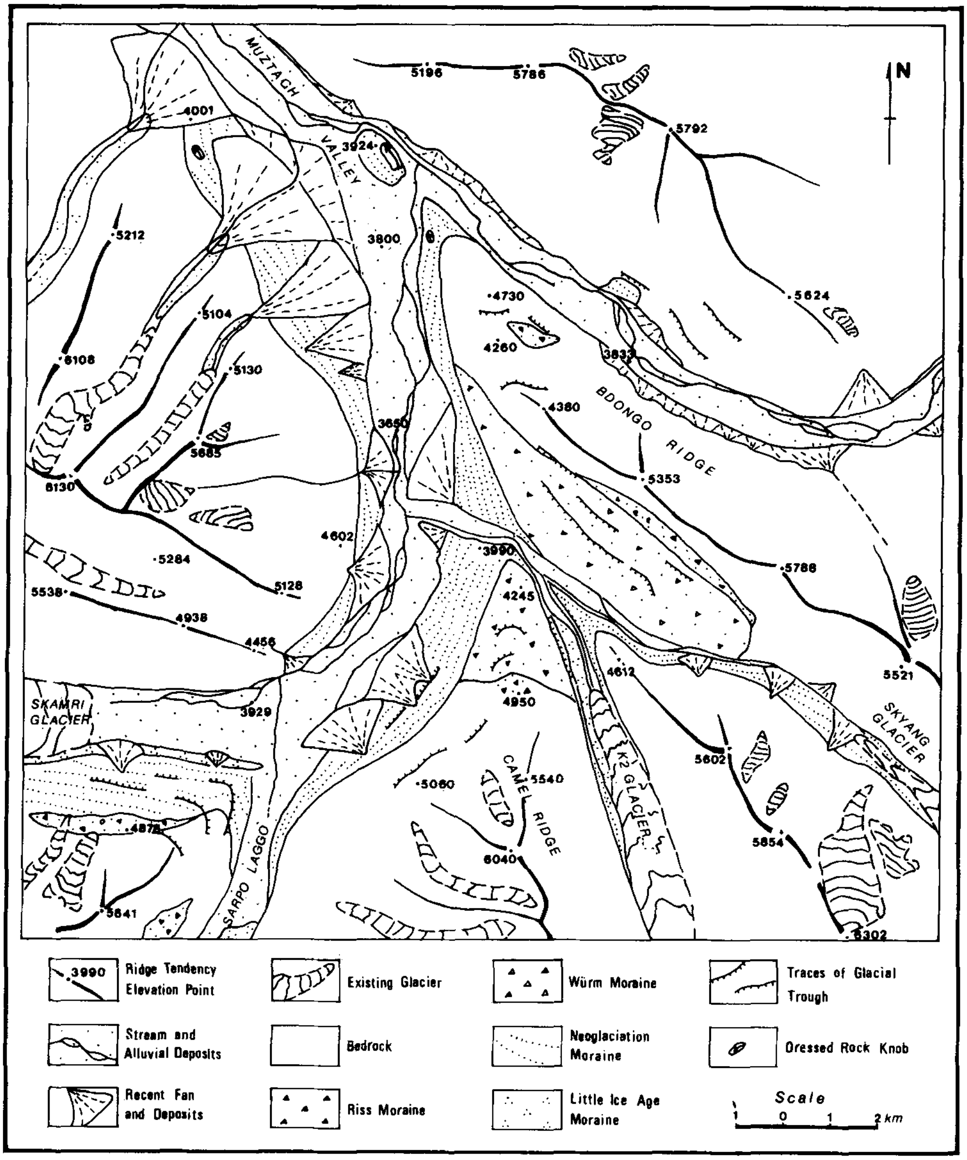


Fig 2
Sketch map showing glacio-geomorphology in Muztagh valley

shaped valley. The fifth surface, used by the present river, displays a young lateral moraine in the Muztagh valley.

Traces of Quaternary Glaciation

The Muztagh Valley

The Muztagh valley is some 2 km wide at 3800 m asl near the junction to the Shaksgam valley. Further upstream above 4000 m are four large glaciers: Yinsugaitti, Sarpo Loggo, N K2 (Qogir) glacier and Skyang glaciers. There are well preserved valley steps and moraines on the Camel ridge and the Bdongo ridge E of the valley (Fig 2). Quaternary Glaciation in this region was studied by A. Desio, Wang Zhichao and other scientists.

Traces of Pleistocene Glaciation

There are three terraces on the Camel ridge and the Bdongo ridge (Fig 3). They face each other on both sides of the K2 glacier valley at 300 m, 800 m and 1200 m above the valley bottom or 4200 m, 4700 m and 5100 m asl respectively. Three moraines on the terraces indicate three glacial stages. Upwards, the first and the second moraine, have similar characteristics in deposition and texture. The moraine thickness decreases from more than 60 m in the lower part to several meters. The bottom part of the moraine is slightly calco-cemented. Light stratification is found in some parts of the lower moraine

Fig 3

where denudated to cliffs and towers. The upper part of the moraine is quite loose and gives a feeling that the lower part is older. The roundness of gravels is mostly subangular. They consist of granite, granitic gneiss, marble, limestone, slate and show some weak weathering. The moraine age is tentatively referred to the Late Pleistocene (Würm), and is divided into two glacial stages (IV1 and IV2) by the moraine depositional features and altitudes.

At first we discovered an old moraine (thickness at least is over 30 m) at 5000 m asl in the Bdongo ridge (Fig 4). The moraine is cemented very hard, the weathering surface is of brown-yellow colour. The profile shows a thick unsorted and unstratified deposit. The maximum diameter of erratic boulders is over 3 m; they have mostly angular and subangular shape. Most boulders are of marble and limestone, some of slate and gneiss. Comparing to the moraines on the lower ridge, the content of marble and limestone of this moraine is higher. Much material of this moraine may be characterized as supraglacial tills. The altitude of the moraine suggests a Riss-age. Besides, we unexpectedly found some boulders of the "Urdok Conglomerate" (Desio, A. 1980) in the proglacial valley of Skyang glacier. Because the clastic deposits did not occur in the moraines of two other glaciations mentioned above, we conclude that the deposits represent a higher geomorphic level, possibly belonging to the sediments of the Early Pleistocene. The Urdok Conglomerate is distributed mainly in the source area of the Urdoc glacier and the upper Shaksgam valley. Small amounts of the Conglomerate also outcrop in the source area of K2 glacier. If these clastic deposits were transported from the Urdok glacier, they must have passed through the saddles of the mountain chain with elevation of over 5600 m, and if the conglomerate was transported from K2 glacier, it must have also crossed a transfluence of 6000 m. The source of the conglomerate has not yet been secured.

Holocene Moraine and Glacier Fluctuations

A young lateral moraine is found on the slopes of the valley below the first terrace. The moraine extends from the valley floor to the edge of the first terrace and about 300 m above. Downwards to the junction of the Shaksgam valley, the difference drops to 200-150 m. The lateral moraine is fresh in shape, in places 10 to 50 m thick or more, some tens to 200 m long, and the moraine ridge is round shaped.

A. Desio has described the lateral moraine with a relative height of 300-400 m in proglacial valley of the

Fig 4

Fig 5

Baltom glacier and the Perdora glacier which could be associated with the lateral moraines of the existing glaciers. However, he believed that the moraine dates of the Last Glaciation. Wang Zhichao (1983) also estimated the age of the moraine as belonging to the Last Glaciation.

The lateral moraine could join the lateral moraines of the existing glaciers further up. Its distribution and shape are similar to post-glacial moraines of the Tibetan plateau. Thus, we conclude that this moraine is of the Neoglacial age. The Neoglacial lateral moraine stretches right up to the Shaksgam valley. In the K2 glacier and the Yinsugetti glacier valleys, besides the lateral moraine of the existing glaciers associated with this moraine, in the ice tongue zone we also found the lateral moraine some 200-300 m above the ice surface in the upper-middle reaches of the glaciers. This moraine probably belongs to the Neoglaciation as well. From these observations it follows that the glaciers have retreated since the Neoglaciation and lost 200-300 m in height.

Fig 6

The data of glacier fluctuations of the Little Ice Age can be obtained from the results of the foreign expeditions starting with 1861 (Godvin-Austen, H.H. 1861; Younghusband, F.E. 1887, 1889 and 1892; Mason, K. 1926; Danielle, G. 1928; Desio, P.A. 1929; etc.). In the early 20th century the glaciers were generally advancing till 1923-1924 and 1929. From this time on the glaciers retreat. May be this was the last fluctuation of the Little Ice Age. The meltwater runoff of the glaciers in the area investigated is very strong. The end moraine of the glacier was rapidly wiped out, therefore the farthest advance during the Little Ice Age is difficult to find. Wang Zhichao (1983) believed that the retreat of the glacier was 2.75 km since the Little Ice Age judging by the relic end moraine in the proglacial valley of K2 glacier (located nearby the juncture of the Skyang glacier valley). However, A. Desio found that in 1929 the K2 glacier valley was blocked near the junction with the Muztagh valley (Desio, A. 1930). It descended for another 1000-1200 m during Neoglaciation and for 600 m during the Little Ice Age.

The end moraines of the large glaciers in the Muztagh valley are usually short and arc shaped. The end moraine of the K2 glacier has a sharp crest alternating with overflow incisions. The present lateral moraine is poorly developed. Many dead ice blocks occur at the terminus of the Sarpo Laggo glacier shaping the present end moraine.

The Shaksgam Valley

The Shaksgam valley bottom is located at 3700-3900 m asl, and 800-1200 m wide. Unstable kettleholes and a net of runs in summer often filled with meltwater make the surface topography quickly changing. Alluvial fans of terraces at the front and at the rear ends rise, respectively, 50-100 m and 200-300 relative to the bottom, and are scattered on the sides of the bottom. Other sections of the valley consist of vertical cliffs with relative height being equal to the depth of erosion after deglaciation.

Outside the valley the glaciation is mainly represented by roches moutonnees and polished rocks, young moraines are occasionally found along the walls of the valley. All the roche moutannees in the river bed down from the confluence of the Shaksgam valley and the Urdok glacier date from the same period as the Knob (160 m high) at the mouth of the Muztagh river. According to the photos (Desio, P. A. 1980, Plate ix, Fig 2), these surfaces are considered as the trough bottom of the Last Glaciation. The tills, surrounding these surfaces and found by Desio, are of postglacial age. They are not distributed continuously at the Shaksgam valley and are related to the tributary glaciers extending to the main valley.

The multistage U-shaped valley at the upper reaches of the Shaksgam river (Fig 5) may be related to the terraces of the Muztagh valley. The trough cliffs of the Last Glaciation are characterized by distinct polished

Fig 7

Fig 8

surfaces (Fig 6) and extend up to 5000 m asl. The thickness of the glacier was estimated as 1200 m.

All the well preserved cirques lie above 4600 m asl, however, a few remnants of cirques are found at 4200 m asl. Among them is a huge concave below a transfluence across the Bdongo ridge with a steep backwall and filled with morainic deposits. The lowest level may be taken as the snowline of the Last Glaciation, and the 4200 asl cirques may represent that of the earlier times. The snowline descended to 1000 m and 1460 m respectively during the Last Ice Age.

The Aghil Pass and the Aghil Range

The crest beside the Aghil pass (4776 m asl) is framed by ridges of about 6000 m asl. Northward from the pass is a wide U-shaped valley with a bottom covered with gravel and boulders (Fig 7). A lateral moraine extends along the left side of the valley. Hanging valleys and polished bedrock are also found here. On the pass well rounded gneiss boulders were found (Fig 8), which were formed by subglacial and preglacial runoff. In 1937 (Shipton, E. E.), the trough north of the pass was lake-filled over 2.4 km instead of less than 0.5 km now.

East of the Aghil pass a fairly levelled bottom stretches discontinuously northwards from the Shaksgam valley. It is the geomorphological level III descending from 5000 to 4600 m asl. It is a remnant of the glacial trough of the Middle Pleistocene, when a tributary glacier from Shaksgam valley entered the Yarkant valley. Here, the latest glacial traces were formed during the Late Pleistocene. Since no firn basin is found above the pass, it appears most likely that an outlet ice flow from the Aghil ice cap once came across it.

From the lower reaches of the Surukuwat valley to the Yarkant river bank a glaciofluvial terrace was formed in the valley below 4200 m asl to the N of the Aghil pass. The thickness of the terrace is from 150 m in the upper reaches to 30-50 m in the lower reaches. In the upper reaches unstratified and unsorted mixed deposits are distributed, containing mostly edged or subedged gravels, the largest having a diameter of 0.5-1.0 m. At the banks of the Yarkant river fine grained deposits display some sorting, roundness and stratification. The bedrock outcropping from the terrace was polished and striated (Fig 9). The knobs on the glaciofluvial terraces of the Yarkant river bank look like roche moutonnees. Compared to the Holocene alluvial fans and terraces of the Yarkant valley, these outwash deposits were formed after 12,000 BP. A conglomerate terrace exists at 3600-4000 m asl near Hishamarl (Kashmir) on the W slope of Karakorum. It is widely spread in the Kara Kunlun mountains. This conglomerate was deposited by the outwash during the glacier retreat of the Last Glaciation.

The present glaciers of Mt. Aghil terminate at about 5000 m asl near the large headpools of modern rivers and shallow valleys in glacial troughs. In the peak zones glaciers pour out from cirques and troughs. Most horns are blade shaped. Paleo-troughs, not related to modern firn basins, parallel modern rivers. The Maleikgatak paleo-trough in the headwaters area of the Yarkant river is 40 km long, its bottom being at 5200 m asl, 400 m above the Yarkant river bed. Another typical paleo-trough lies to the N side of the Shaksgam valley between the Kayajia glacier and the Gasherbrum glacier. Its bottom is 600 m above the Shaksgam river, it is considered to be the location of the early Shaksgam river (Mason, M.K. 1927). Due to the uplift from SW to NE, most paleo-troughs are found NE of the modern valleys. The geomorphological appearances of the Aghil mountains show most impressively that they were just released from an overall ice cover. Moreover, there is no large periglacial landform, though the conditions are favourable for their development just above the lower boundary (4600-4800 m asl) of perennial permafrost.

The Yarkant River

The 10 km long section of the Yarkant valley upwards from Ilik (the confluence of the Surukwat valley and the

Fig 9

Yarkant river) is a gorge cut by the present stream. The lowest troughs lie here at 4000 m asl, 400 m above the today stream, corresponding to the Last Glaciation in the Muztagh valley.

A 5 km long moraine with a series of level rims runs along the N side of the Yarkant river near Ailikeshalati. The lowest part of moraine is covered by a young alluvial fan (Fig 10). A piece of rotten wood was recovered from this fan. Its C^{14} age is 12,800±230 BP (Shen Yongping). At another site, 15 km upstream from Maza, an isolated hill, rising 500 m from the river bed, is covered by 5-6 m of moraine deposits belonging to the Last Glaciation. This knob consists of clays of the Early Paleozoic Era; gravels contain granite, marble, limestone and sandstone.

Obviously, a major valley glacier existed in the Yarkant valley during the Last Glaciation. In Postglaciation the Yarkant valley has been dissected by 400-500 m, compared to only 200-300 m in the Shaksgam valley. This may be due to the fact that the Yarkant glacier retreated earlier than in the Shaksgam, and the tributary glaciers did not reach the main valley in Yarkant during the Postglaciation.

The West Kunlun Mountain Region

In this alpine region the ridges with average elevation of 5500 m asl may represent the geomorphologic surface I, below which several wide valley surfaces with respective elevations of 5200-5000 m, 4800-4600 m and 4400-4000 m asl can be distinguished. These surfaces descend to lower reaches and respectively belong to geomorphological surfaces II, III and IV. The most developed surface lies at 4800-4600 m asl, up to 10-15 km wide. At 4000 m asl in front of the alpine region, the lowest paleocirques are found in groups, single cirques stretch down to about 3800 m asl. The lowest snowline was 1600 m lower than today. According to the calculation method of H.Höfer the lower boundary of glaciation should be expected lower than 2000 m asl.

Although we have found U-shaped valleys and polished bedrocks on the valley sides in a moderately high mountain region (4000-3000 m asl), no distinct evidence of moraines was obtained probably because of the fluvial erosion or overlay of modern deposits.

In a loess-covered hilly region of the piedmont belt loess is distributed up to 3500-3800 m asl. At the beginning, loess covered the bedrock (limestone) directly. Unstratified and unsorted gravel layers lie between loess and bedrock below 3000 m asl (Fig 11). The pebbles, seen along the expedition route, are composed of a wide range of rocks and patterns. Among them we found basalts with almond-shaped filler which was not reported before. Moreover, few of the boulders look very much like the Urdok Conglomerate, mentioned above, in both surface characteristics and rock composition. It is difficult to conclude if the boulders came from Karakorum because we do not know well all the rock types and their stratigraphic distribution in this region.

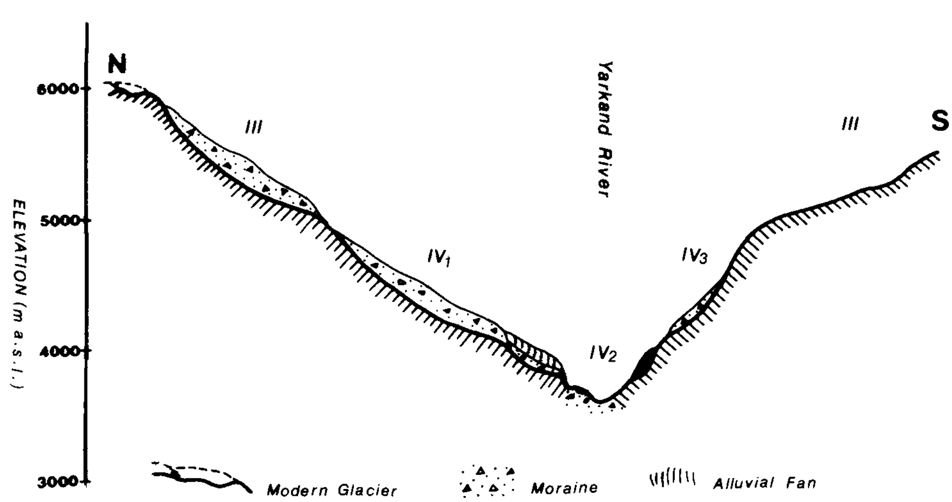


Fig 10
Quaternary glacio-geological profile at Ailikeshalati in Yarkant valley

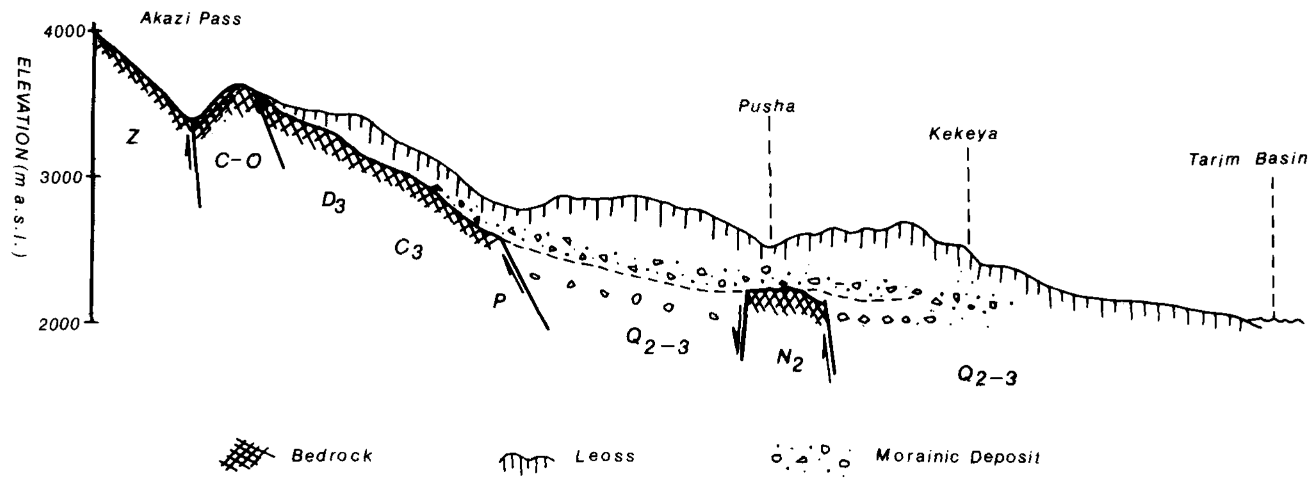


Fig 11 Sketch profile of geomorpho-geology in the piedmont of W Qunlun

At the W of the highway, 6-8 km up from Pushu village, a 40-50 high Quaternary profile is exposed. The lower part consists of a massive irregular silty sand layer with weak calco-cement and a depth of about 1-2 m (samples were collected for TL dating). The upper part is a 4-8 m thick sand-gravel deposit with quite irregular stratification, poor sorting and roundness, intercalated fine silt and a coarse gravel layer (gravels diameter of 0.5 to 1-2 m). The top part is presented by unstratified and unsorted gravel deposits, occasionally having fine sand layer-like stratification, intercalating a large amount of 1-2 m diameter boulders. The depositional appearance suggests to classify these sediments as morainic. The age of the moraine is provisionally defined as of the Middle Pleistocene.

Conclusions and Discussion

Uplift and Conditions of Quaternary Glaciation

Since the average elevation of the Aghil ridge is 6000 m asl, the primary surface of the Pleistocene on the N slope of Mt.Qogir is 500-1000 higher than the centre of the Tibetan plateau. Adding 500-1000 m to the uplift of the Tibetan plateau in every Epoch of the Quaternary, the elevations of the N slope of Mt. Qogir should have been 2500 m asl in the Early Pleistocene, 3500-4000 m asl in the Middle Pleistocene and 4500-5000 m asl in the Late Pleistocene. Even in the Early Quaternary the distribution pattern of lands and seas as well as atmospheric circulation was about the same as today. With the uplift of the plateau, the vapour transit increased along the meridian line. Obviously, the topography of the plateau in the Middle Pleistocene and the Late Pleistocene were favourable for the development of glaciers. Until the Late Pleistocene the uplift distinctly influenced precipitation on the N slope. Relative precipitation on the N slope of the Kara Kunlun mountains remained more than 1000 mm per year.

According to the estimated elevation and glaciation temperatures of the different epochs the annual temperature at firnline during glaciation of the Middle Pleistocene should have been −3 to −5°C, while the modern firnline temperature is about −10°C. At least the mean annual precipitation was about 3000 mm since the elevations were located just at the maximum precipitation belt. The conditions at this time were more favourable for the development of glaciers than those in the Alps during the Ice Age, when the snowline descended lower than 1500 m asl. In the Late Pleistocene the mean annual temperature was about −4 to −6°C and the mean annual precipitation reached 2000 mm.

Snowline and the Lower Limit of Glaciation

The present snowline lies at 5600 m asl on the N slope of the Kara Kunlun mountains and is a bit higher than in the West Kunlun mountains. Above the snowline, paleocirques overlap one another and have no stratification. The lowest limit of these well shaped cirques at 4600 m asl was formed during the Last Glaciation. The downmost cirque is located at 4200 m asl in the Shaksgam valley, the Yarkant valley and at 4000 m asl of the West Kunlun mountains. Having been destroyed intensively, fewer cirques at 4200 m asl have remained in the Shaksgam and the Yarkant valleys, while paleocirques in groups are numerous in the West Kunlun mountains. We consider the cirques at 4200-4000 m asl to be residues of the Middle Pleistocene Glaciation. Thus, the snowline had descended by 1000 m during the Last Glaciation and by 1600 m during the Middle Pleistocene Glaciation. The earlier cirques have been covered by the main valley glacier during the Last Glaciation which resulted in fewer cirques at 4200 m asl in the Kara Kunlun mountains.

Except for some large glaciers in the Muztagh valley most of the existing glaciers terminate at 4800-5200 m asl as calculated by the method of H.Höfer (supplemented by M.Kuhle, 1987). The lower boundary of the Middle Pleistocene Glaciation would be lower than 2000 m asl as that of the Last Glaciation would reach about 3000 m asl. It is easy to accept that a large valley glacier existed at the Shaksgam and the Yarkant rivers but not in the case of piedmont belt of the West Kunlun mountains. On the basis of the visual data scholars prefer to consider the gravel deposits beneath 3000 m asl in front of the Kunlun mountains as alluvial sediments, rather than moraine, due to the later erosion. Not much evidence for this could be obtained; it still needs to be confirmed.

The later descent of the snowline during Postglaciation is difficult to determine from the elevation of the cirques, but end moraines of some little valley glaciers can be recognised on the aerial photos. End moraines of the New Glaciation and the Little Glaciation respectively descended to 3800 and 4400-4200 m asl, their snowlines lowered by 600 m and 300-400 m respectively.

The Age of Glaciation and Glacier Type

Absolute age of the Quaternary sediments in Karakorum is very hard to determine. The TL samples were collected during the joint expedition systematically but up to now only two of C^{14} analyses indicated the depositions as postglacial. Determination of glaciation age still needs the application of traditional geomorphological methods. At present there are nine or more glacial-interglacial cycles to be reconstructed from the deep-sea sediment core and loess-paleosoil sediment sequence, but the characteristics of the multiform level and its relevant sediments represent not only a tectonic upheaval but also eustatic and land-load change restricted to the tectonic uplift. Thus, the geomorphic mark has comprehensive significance in the classification of the Quaternary age. The key problem is to use modern technology of determining the absolute age of the sediments as much as possible.

We classified the geomorphic surface and the age of glaciation by the moraine features and depositional texture of the Muztagh valley. The geomorphic surface with the elevation of 5000 m descended in the Middle Pleistocene, which is indicated by an older moraine, found on this level, which contains calco-cement and differs from loosen moraine located below the surface. Evidence for the Early Pleistocene geomorphic surface is given by some boulders of the Urdok Conglomerate. This aspect needs further investigation.

As was mentioned above, ELA had dropped to 1600 m in the Middle Pleistocene, and the landform altitude at that time was 3500-4000 m. If the river cut rate was only half of the uplift rate, the depth of the Shaksgam valley and the Yarkant valley has not exceeded 1500 m. The ELA descended below the valley bottom. The whole N slope of the K2 Mountain with Karakorum in the centre formed a glacial sheet, and many spill glaciers flew into the present middle-low mountain zone down to the piedmont.

The glaciation range of Late Pleistocene was quite large. There was a large-scale ice cap above the elevation of 4600 m (equilibrium line altitude of the Last Ice Age) with its centre in the upper Shaksgam and upper Yarkant valleys. During the Last Glaciation the Shaksgam valley and the Yarkant valley accommodated huge valley glaciers. At the same time, many subsidiary glaciers developed in the Aghil pass valley and other valleys, and many troughs were formed beneath the ice cap.

The Tectonic Uplift during the Post-Glacial Period

The tectonic uplift of the Postglacial has clearly tilting characteristics from SW towards NW. This can be shown by divides of all the mountains located at the SW part of various fault blocks, by gully captures, by the fans formed of alluvial deposits as well as by the valleys parallel to the tectonic line which points to the SW. The troughs of the Last Glaciation have risen by 400-800 m comparing to the present valley floor. The altitude of the Shaksgam valley floor descended by 200-300 m below the rear margin of the alluvial fan in the study area. In the tributary valleys of the Aghil ranges, such as the Zug Shaksgam valley, the upper-middle valley undercut about 100-200 m and 300-400 m of the lower valley. The Yarkant valley undercut 400-500 m. The undercutting depths of various valleys are controlled by the tilting, tectonic fault depression and time of glacier retreat as well as by other factors. If we take the average undercutting depth in this region as 300-400 m and estimate that the uplift amounts up to 600-800 m during the postglacial period then this uplift rate (50 mm/year) will greatly exceed the mean rate of the Pleistocene uplift and recent geodetic value. Perhaps this value, to a great extent, reflects the rebound characteristics of the postglacial period.

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Precipitation Conditions for the Development of the Present Glaciers on the Norhtern Slope of Karakorum

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ABSTRACT: Many of the present glaciers were perfectly developed on the northern slope of the Karakorum mountains. Different explanations of the material foundation of the glaciers' development are given owing to limitation of the data measured. This paper analyses the changes of precipitation with altitude and the relation between precipitation and glacier distribution. The study shows that precipitation increases rapidly with altitude from the valley floor at about 4000 m asl, which results in higher precipitation in the firn area. Annual accumulation at equilibrium line comes up to 800 to 900 mm in the head of the Yarkant valley and 1500 to 2000 mm around Qogir area.

Approach to the Problem

Many of the present glaciers were developed completely on the N slope of the Karakorum mountains which is located in the upper reaches of the Yarkant valley. Insukati glacier, the biggest glacier in China, is situated in the W of Mt. Qogir (K2), the second highest peak in the world. Although mountaineering and scientific expeditions were frequent, we know very little about precipitation and glacier development in the area. Most explorers estimated precipitation in the glacier areas according to the data from the foot of the mountain or low and medium altitude where precipitation is much lower. On the S slope annual precipitation is about 130 mm in Gilgit at 1500 m asl and only about 100 mm in Misgar at about 3100 m asl (Lui, G.Y. 1980). On the N slope annual precipitation is 90 mm in Kulukelangang at 1840 m asl and only about 70 mm in Taxkorgar at 3091 m asl. Precipitation decreases with a rise in altitude in the low and medium high mountain areas. Obviously, if precipitation in the glacier areas with altitudes of 5000 to 6000 m asl is estimated by the data from the areas mentioned above, large errors will occur. The vertical change of precipitation is nonlinear, thus, the belt of minimum or maximum precipitation may appear at a certain altitude. Recent investigations in the Shaksgam river region showed precipitation to be very little in the valley areas at about 4000 m asl on the N slope of Karakorum. Precipitation in the area was estimated to be less than 40 mm (Wang, Z.C. 1983a,b). Similar results were obtained for the valley bottom in the upper reaches of the Yarkant valley during the flood expedition from 1985 to 1986. However, due to the lack of field data, some divergences exist in precipitation changes from the arid alpine valley to extreme alpine area where many glaciers were developed. According to the climate in the alpine valley, Wang Z.C. (1983a,b) inferred that annual precipitation never exceeds 300 mm near the equilibrium line of extreme alpine belt. Shi, Y.F. (1984) did not agree with this estimation. Abundant heat and strong solar radiation resulted in strong ablation in the area located at lower latitude. If precipitation was less than 300 mm, it is difficult to explain why so many glaciers, of which some are large valley glaciers with length of more than 20 km, exist.

Vertical Changes of Precipitation in the Glacier Areas

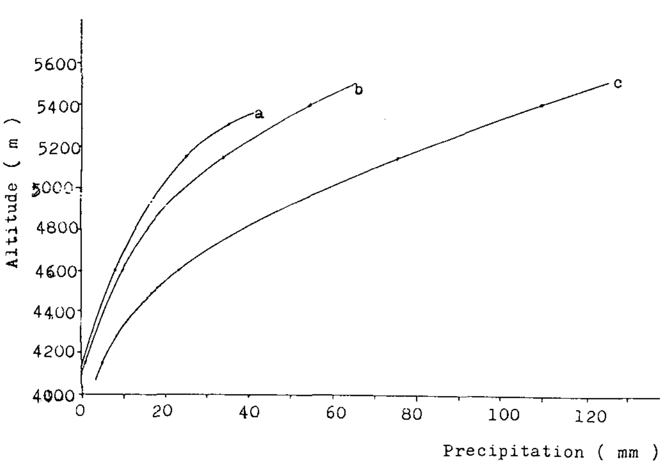
Fig 1 shows vertical changes of precipitation measured in K2 glacier in September, 1986. Precipitation began to increase with altitude from the glacier terminus at about

Altitude (m asl)	Date	Precipitation (mm)	Times	Remarks
4150	06.09–17.10	2.2	7	precipitation for 4 times only 1.2 mm
4600	11.09–08.10	31.8	15	
5150	11.09–08.10	94.0	15	
5400	13.09–27.09	108.9		by pots

Tab 1
Precipitation measured on the Qogir glacier

4100 m asl and, the higher the altitude is, the more rapidly precipitation increases. Such a rise in precipitation certainly results in huge difference of precipitation between the firn area and the terminus (Tab 1). From September 11 to October 8 precipitation was only 1.2 mm at the terminus, but 94 mm in the upper part of the ablation area at 5150 m asl, which means that the difference in precipitation reaches almost 80 times. Much bigger difference may occur between the glacial terminus and the firn area above 5400 m asl. Between the terminus and the firn area obvious difference exists not only in precipitation intensity but also in precipitation times. The ratio of precipitation times is 1:3.75, which means that precipitation occurs in the terminal area only once while it occurs nearly 4 times in the firn area. Hence, during expeditions weather is often fine down in the valley but is clouded in the firn areas in Karakorum. American mountaineering team was besieged by a windstorm and heavy snowfall for more than a month from July to August 1986 at the height of 7400 m asl during their climbing to K2. Weather made their hope of reaching the peak turn into nothing. However at the same time, precipitation in Mazar area at 3800 m asl in the Yarkant valley was very small.

Fig 1 The vertical changes of precipitation in the K2 glacier in September 1986. a) September 27th; b) September 13th; c) September 13th to 21st.



In other regions similar differences in precipitation also exist. Precipitation was found to be about 100 mm in the valley below 3000 m asl in the W side of Karakorum from 1974 to 1975. However, precipitation increased rapidly with altitude. The annual precipitation was 1300-1500 mm near the equilibrium line at 5000 m asl (Lui, G.Y. 1980). In the Mt. Qomolangma area the maximum precipitation occurs between the altitudes of 6500 and 7000 m above the equilibrium line, and the annual precipitation is twice of that (335 mm) at the altitude of 5000 m (Xie, Z.C. 1975; Gao, D.J. 1979). Near the head of the Urumqi river of Tianshan, annual precipitation is about 430 mm close to the glacial terminus at 3539 m asl, and 650 mm at equilibrium about 4000 m asl. In Tianshan, Qilianshan and Pamir, where many glaciers are concentrated, the rapid increase in precipitation with altitude has also been found.

Thus, it can be seen that the reincrease of precipitation in the glacier area is of general significance. The reasons for precipitation reincrease in the glacier area are complicated. Here, however, is no room for further discussion of this phenomenon. Nevertheless, we can get some explanations from the change of relative humidity. The glacier itself is a cold source, especially in the firn area, where the albedo of the surface is so strong and the effect of air on temperature increase is so small that lower air temperature will be formed. The lower air temperature makes the saturation vapor pressure above the firn area to decrease and the vapor which is transported from the upper air into the firn area is saturated easily. Therefore the relative humidity should increase (Fig 2 and Tab 2). It can be seen from Fig 2 that the increase in mean relative humidity with altitude is linear. Tab 2 shows the accumulative time, during which certain relative humidity occurs in the observation period (from September 22 to October 6, 1986), and the percentage of the accumulative time to the total observation time (15 days). For example, when the relative humidity exceeds 80% the accumulative time is 9.62 hours, which makes only for 2.7% of the total observation time in the glacial terminus. However, the accumulative time for the relative humidity of more than 80% amounts to about 105 hours near the equilibrium line, which means that the relative humidity is more than 80% in the time which occupies 29% of the total

Position (m asl)	Relative humidity				
	100–80 hrs/%	79–60 hrs/%	59–40 hrs/%	39–20 hrs/%	19–0 hrs/%
4150	9.6/ 2.7	72.2/20.1	119.5/33.2	145.7/40.5	13.0/3.6
4600	55.3/15.3	60.8/16.9	132.8/36.9	101.0/28.1	10.0/2.8
5330	105.0/29.0	70.0/19.5	164.2/45.6	21.2/ 5.9	0.0/0.0
mean	56.5/15.7	67.7/18.8	138.8/38.6	89.3/24.8	7.7/2.1

Tab 2 Relative humidity at various altitudes in the K2 area

observation time. The degree of vapor saturation was observed to be much higher in the firn area than at the terminus. This indicates that the possible precipitation rate of the vapor above the firn area is higher.

Relationship between Precipitation and Glacier Development

The Karakorum range is situated on the W side of the Qinghai-Xizang plateau. The upper vapor, brought by westerlies and the SW monsoon, can intrude through the passes or be intercepted by some protruding mountain peaks. Although the content of upper vapor may be small, lower temperature in the firn areas can make vapor to saturate and condense much quicker so that precipitation is probably produced. The direction of vapor transport,perhaps, has some effects on the direction of the firn basin (Fig 3). The direction of the firn basins first points to NE, and then, on the N slope of Karakorum, to SW. The direction of the main range

Fig 2 Changes of the relative humidity above the K2 glacier (Relative humidity mean value from 22.09. to 06.10, 1986) a) minimum; b) mean; c) maximum.

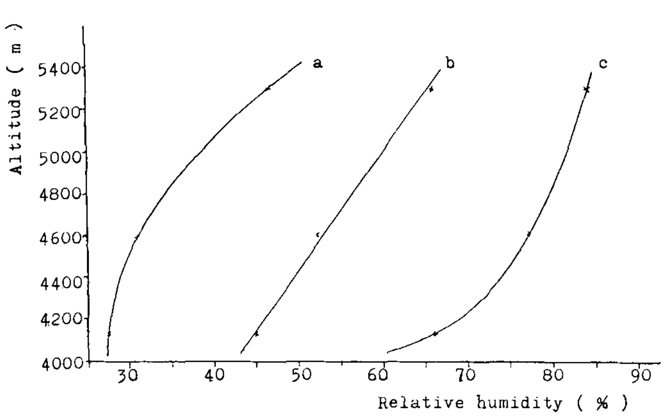
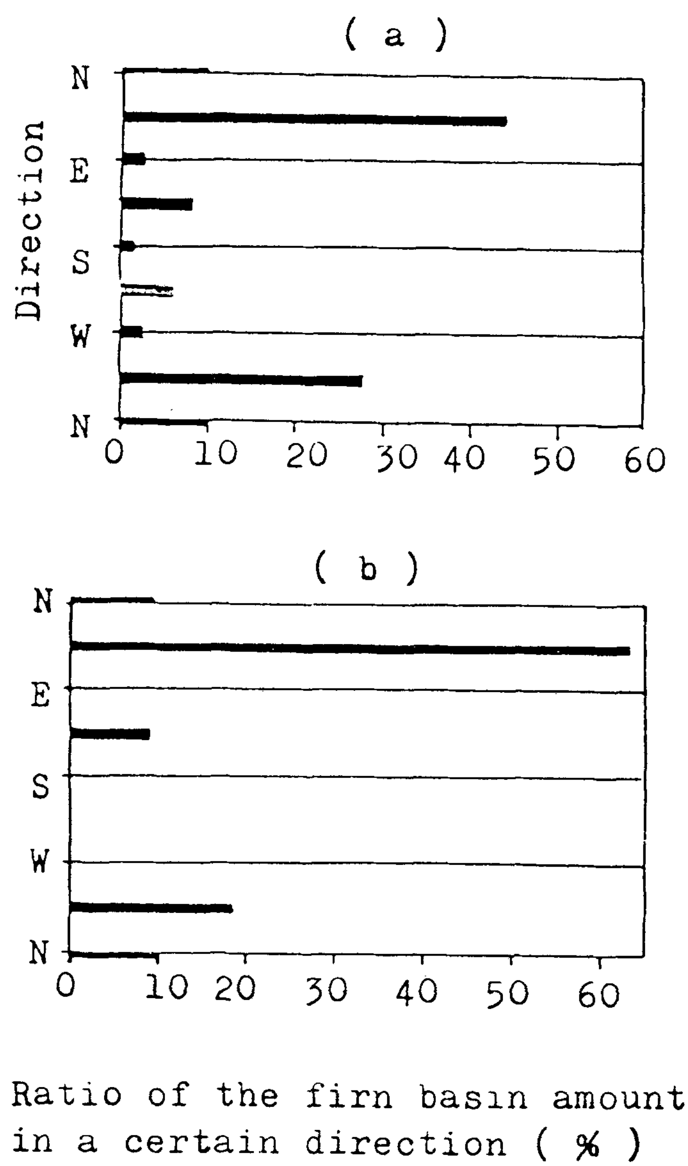


Fig 3 Directions of the firn basins on the N slope of Karakorum: (a) Yarkant river drainage area; (b) For the glaciers larger than 70 km^2 in Shaksgam river drainage area.



Glaciers	Length (km)	Area (km^2)	Equilibrium line (m asl)	Terminus (m asl)	Tongue height (m)	Glacier height (m)
Rimn	20.7	76.7	5660	5340	320	980
Kyargar	20.8	105.6	5420	4760	660	2483
Taramkangri	28.0	124.5	5400	4550	850	2891
Stanger	27.8	83.5	5200	4430	770	2742
Gasherbrum	26.0	119.8	5500	4350	1150	3701
Sarpolaggo	29.4	196.7	5230	4100	1120	3310
Qogir	21.3	91.2	5400	4160	1240	4451
Insukati	42.0	379.9	5360	4000	1360	3285
Braldu	35.5	133.5	4900	3920	980	2182

Tab 3 Distribution of some large glaciers

of Karakorum appears to be from NWW to SEE. For this direction an optimum angle between the main range in the NE direction and the vapor from the W exists, which is favorable for vapor intrusion and interception. This shows that the W vapor from the Atlantic air flow is far from the study area. However, it can get into the study area through lower mountains because the vapor is supplied from the Mediterranean, the Black Sea and the Caspian Sea, and the W air flow above the troposphere of Xinjiang is unblocked all the year round. Therefore, vapor in this direction is more abundant. The distribution of the glaciers reflects the direction of vapor transport (Tab 3). Glacier size gradually decreases from W to E. it is evident that the altitude of the equilibrium line and the terminus increase, the zone of glacial activity and tongue extension narrows eastward, though the difference is small.. The dependance of the glaciers on precipitation is also reflected in the distributive altitudes of the glaciers (Tab 4). It could be seen that the more there are mountain peaks, the more there are glaciers. The peaks, for example, collect vapor from the Indinakori pass to the W of Insukati, and, consequently, glaciers are concentrated here. The mean length of glaciers in Tab 4 is the ratio of the glacial area to distance. It means that the glacier length listed in Tab 4 will be formed if the glaciers are extended along the N slope from W to E. For example, a glacier, 416 km wide and 5.15 km long, will be formed if the total glacial area of 2144 km^2 is divided by the distance of 416 km. The peaks of more than 6000 m asl have direct effect on the glacial growth. In the section from the Indinakori pass to the W side of Insukati, in the center of which Mt. Qogir is situated, the peaks of more than 6000 m asl are densely distributed, one peak per 5.47 km along the range (in average one peak per 8.32 km). In every place, where the glaciers concentrate from the Karakorum pass to the Kurijirap pass, peaks of more than 6000 m asl must exist. This feature of glacial distribution reflects the changes in precipitation in space to a certain extent, indicating that higher mountains are quite important for alpine

Tab 4 Relation between mountain peaks and glaciers

Section	Distance (km)	Area of glacier km^2	Area of glacier %	Peaks above 6000 m no.	Peaks above 6000 m %	Mean length of glacier (km)	Glacier of > 10 km no.
Karakorum pass to Indinakori pass	125	730	34	14	28	5.84	4
Indinakori pass to W side of Insukati	186	1200	56	34	68	6.54	8
W side of Insukati to Kurijirap pass	105	214	10	2	4	2.04	0
Total	416	2144	100	50	100	5.15	12

Names of glaciers	Ts (°C)	Ablation (mm)		Precipitation (mm)	
		Equation (1)	Equation (2)	Equation (1)	Equation (2)
Rimn	−0.6	820	710	630	550
Nan pass	−0.2	930	800	710	620
Kyargar	1.2	1350	1190	1040	920
Taramkangri	1.1	1320	1160	1020	890
Stanger	1.6	1500	1320	1150	1020
Gasherberum	0.9	1260	1100	970	850
Sappo Laggo	2.1	1690	1500	1300	1150
Qogir	1.5	1460	1290	1123	9990
Insukati	1.7	1540	1350	1180	1040
Braldu	2.9	2030	1800	1560	1390

Tab 5 Accumulation and precipitation at the equilibrium line. Precipitation is estimated by coefficient 1.3 (Kotlyaker 1982)

precipitation. Because of the fact that precipitation still rises with altitude near 5400 m asl (Fig 1), an abundant precipitation belt may be formed above 6000 m asl. Therefore, the peaks of more than 6000 m asl effect glacial development obviously. Because of the lower latitude and strong heat, the isotherm of mean summer zero temperature reaches 5600 m asl (Ding, Y.J. 1987) and ablation is very strong in this area. Consequently, if precipitation is lower in the firn area, it is impossible for such bigger glaciers to be formed.

Precipitation in the Glacier Area

As a solid form of water glaciers have been existing in the alpine areas for a long time. They are a product of combined effect of heat and water conditions. Thus, many useful climatic records can be obtained from their development and changing. As early as in 1924 H. W:son Ahlman suggested that the accumulation of glaciers at the equilibrium line can be estimated by ablation. Khodakov, V.G. (1975) and Kotlyakov, V.M. and Krenke, A.N. (1982) consummated this concept both in theory and methodology, and widely applied it to the USSR. The accumulation may be easily determined as the ablation at the equilibrium line can be obtained. For this reason, an empirical equation, using the field data from Batura glaciers, was worked out:

$$A = 2.1\ (9.5+Ts)^{2.73} \qquad (1)$$

where A is the mean annual ablation at altitude of the glacier (mm). Ts is the mean summer (June to August) air temperature at the same height (°C). This formula is close to that obtained earlier by Kotlyakov, V.M. and Krenke, A.N. (1982). The so-called global formula is as follows:

$$A = 1.33\ (9.66+Ts)^{2.85} \qquad (2)$$

When Ts is more than −3°C, the difference between the two equations is less than 15%. By using equation (1), the annual precipitation at the equilibrium line in Batura glacier was calculated as about 1600 mm. This result is a little higher than that (1300−1500 mm) obtained from measurements by pots (Lui, G.Y. 1980). Accumulations at the equilibrium line on the N slope of Karakorum were calculated by equations (1) and (2) (Tab 5). Air temperatures in Tab 5 are estimated by correcting the influences of altitude (temperature gradient), macroscopic geographical factors (latitude and longitude) and temperature jump in the glacier (cooling effect), being of better reliability (Ding, Y.J 1987). The tendency that accumulation or precipitation at the equilibrium line decline gradually from W to E can be found from Tab 5. Whether the equation (1) can be applied to the whole N slope of Karakorum needs further testing and more field data. However, some qualitative understanding may be achieved through the following analysis (Ding, Y.J. 1988):

1. According to the comparison mentioned above, the difference of the two equations is not too large for present conditions within a certain range of temperature. According to the temperature range shown in Tab 5, the values calculated by equation (1) are normally 11 to 13% larger than those calculated by equation (2). Equation (2) is more representative because it was developed on the basis of the data collected from most of the stations in the world. But equation (1) may suite more to the N slope of Karakorum. Detailed discussion of this matter are found elsewhere (Ding, Y.J. 1988).

2. The mean annual ablation in the ablation area of K2 glacier in 1986 was calculated to be 2988 mm by using equation (1). The mean melting rate of 7.3 mm/day in September was measured with stakes in the ablation area in the same year. If the meltwater runoff in September makes up 7.1% of the yearly total in the Batura glacier

(Li, J. 1980), the mean value is 3085 mm. This is close to the value calculated by equation (1).

3. On the basis of the data measured in the K2 glacier, precipitation was estimated to be about 84 mm at 5150 m asl in September, 1986. If precipitation in September accounted for 10% of the annual precipitation at the known stations, it can be concluded that the annual precipitation was about 840 mm. According to this value, the annual precipitation at the equilibrium line of 5400 m asl probably comes up to more than 1000 mm. This is similar to that in the K2 glacier (Tab 5).

In addition, high precipitation in the firn area is very important for glacier existence and development on the N slope of Karakorum. Abundant precipitation which occurs on the ablation area has little supply effect on glaciers though it may weaken ablation. Especially when air temperature near the glacier tongue remains high in summer, a rainfall may occur sometimes, which is unfavorable to the development of glaciers. However, it is covered by snow all the year round in the firn area. Snowfall loss is small and snow hardly melts here because of the lower temperature. Therefore, a large share of the precipitation can be converted into ice to supply for glaciers.

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A Giant Avalanche on K2 Mount, Karakorum

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ABSTRACT: On September 16th, 1986, an ice avalanche from a hanging glacier near the K2 peak at 7800 m asl, Karakorum, triggered a massive avalanche of ice and snow. Ice and snow, impacting on the path, formed a dust cloud at the advancing tip. Grounding on the firn basin surface, ice and snow broke into fine powder and covered the whole basin. Fine powder of the dust cloud rose up to 500–600 m and drifted 4–5 km away. On the basis of field observations and measurements, topography and weather, conditions of the avalanche formation are analyzed. Judging by the data obtained, the avalanche was extremely large, its vertical descend being 2500 m, the maximum motion speed 124 m/s, volume of the avalanche mass 2×10^5 m^3 to 10^7 m^3, and impact pressure, as the avalanche grounded, 2.3×10^6 Pa. It could have been one of the largest avalanches ever recorded, causing danger for mountaineering and expedition activities in this area.

Introduction

The K2 region of Karakorum is one of the most dangerous areas for avalanches in the mountain regions of West China. The dangerous period covers all the year round while avalanches are particularly frequent in the warm season, either during or after snowfall. The avalanche ice and snow is one of the major sources of nourishment for glaciers.

At 3:10 pm on September 16, 1986, an ice avalanche from a hanging glacier near the K2 peak of 7800 m asl triggered a massive avalanche of ice and snow. Vertical descent was about 2500 m. Ice and snow impacting after free fall over the cliff band pulverized and formed a dust cloud at the advancing tip. Grounding on the firn basin surface, ice and snow broke into fine powder and covered the whole basin. Fine powder of the dust cloud rose up to 500–600 m and drifted 4–5 km away.

Weather Conditions

In the high mountain zone of the glacierized area precipitation increases with height, forming a high precipitation zone (Shen, Y. P. 1987 a). In summer (May-September) precipitation in the K2 area (Karakorum) may amount for up to 800–1200 mm, which is 70% of the annual precipitation (Shen, Y. P. 1987 b). Daily maximum snowfall may reach 100–150 cm. Precipitation in summer is strongly influenced by the monsoon from India.

In the summer of 1986 weather conditions of the K2 glacier were very bad and storms were frequent. During the period of bad weather from 4th to 15th of September thick clouds covered all the peaks, heavy snowfall and storms above 5000 m asl were observed. On the 14th and 15th of September a snowfall at Camp II at 5200 m asl amounted for 40 cm. Total depth of snow during this weather period was over 100 cm in the area above 5200 m asl. The next day, September 16th, was nice. Sky was blue and cloudless and the sun was shining brightly. Snow cover on the slopes was thick and unstable, avalanches occurred frequently.

Thus, high precipitation during a short period was the major factor for triggering large avalanches. The large avalanche at 3:10 pm on the 16th of September logically occurred in response to a storm period of heavy precipitation (Fig 1).

Geomorphological Settings

The K2 glacier valley is fairly deepened. The altitude difference from the K2 peak (8611 m asl) downward to the

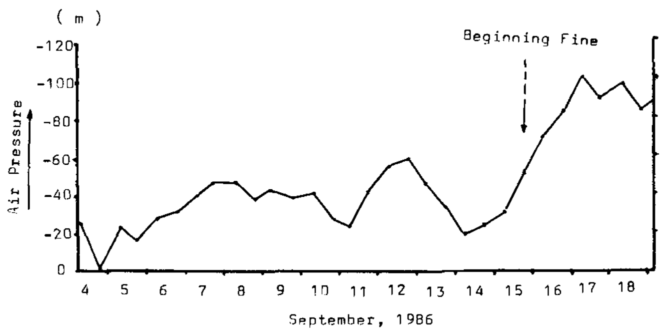

Fig 1 Air pressure is shown as the variation of reading from an altimeter at the base camp (4150 m)

surface of the firn basin is about 3400 m. There are two firn basins at the head of the K2 glacier, the E and the W basin. The E basin is the major firn basin with wall-like round and steep slopes. Slope angles in the basin are mostly 40° to 60°. The N slope of K2 is the steepert, and there is a small hanging glacier at 7700–8200 m asl. Downwards from the terminus of the glacier a very steep channel, the path of the avalanche, is observed. The variation of the peak angle is shown in Tab 1. Orographical features are clearly favorable for avalanche slides (Fig 2). Snow on slopes is unstable. Geometry of the avalanche path, based on the 1:50.000 map, is shown on Fig 3.

Description of the Avalanche

An avalanche path is usually considered to include three zones: the starting, the track and the runout-deposition zone. Dynamic characteristics of the moving avalanche, then, depend on the relief of the track and the amount of material entrained in the avalanche.

Starting Zone

The large avalanche was triggered by an ice avalanche. Generally, ice avalanches originate from where a part of the glacier terminus is situated at a steep slope of a cliff band. In the K2 area the starting zone is a hanging glacier with the terminus at about 7800 m asl. The glacier is 600 m long and 350 m wide, its thickness is only 20–30 m, the vertical height is 400 m. It is situated in a small cirque. The inclination of the ice surface is 33°. The glacier is located at such a high altitude that the accumulation ratio is also high, since the high mountain is situated in the high precipitation zone with the annual precipitation of more than 2000 mm (1000–1500 mm from May to September; Shen, Y. P. 1987 b). Therefore, ice velocity must be rapid; the front of the glacier is deep and irregular in shape. When ice blocks are broken off, the energy of a large ice block dropping down a steeply inclining slope is occasionally strong enough to trigger a massive snow avalanche.

Track

Almost immediately after an ice slab breaks away from the glacier of the starting zone and begins accelerating down the track, the moving mass disintegrates into blocks and later into round chunks, as well as into particles of various size. Ice triggered the snow mass on the track to move and mix with the moving mass block. Ice and snow were placed at high elevation and, therefore, were not melting. Then the small dust-like particles diffused turbulently into a cloud which developed into a descending mass.

Runout Zone of the Firn Basin

Snow and ice moved down and were grounded to fine powder in the firn basin. The advancing tip pushed up a dust cloud which drifted away along the whole basin and up to 500–600 m high. As the avalanche entered the top of the zone it decelerated to rest at the runout distance.

Estimating the Avalanche Data

Using the photo data and maps, we can calculate the avalanche dynamic parameters such as the avalanche velocity, mass, runout distance and impacting force.

Tab 1 Angle of slope in the path of K2

Altitude (m asl)	Slope length (m)	Height (m)	Horizontal length (m)	Angle
7700–7100	660	600	250	53°26'
7100–6600	640	500	400	51°20'
6600–5900	860	700	500	54°27'
5900–5400	707	500	500	45°
Total	2867	2300	1650	53°7'
5400–5200	1513	200	1500	7°35'

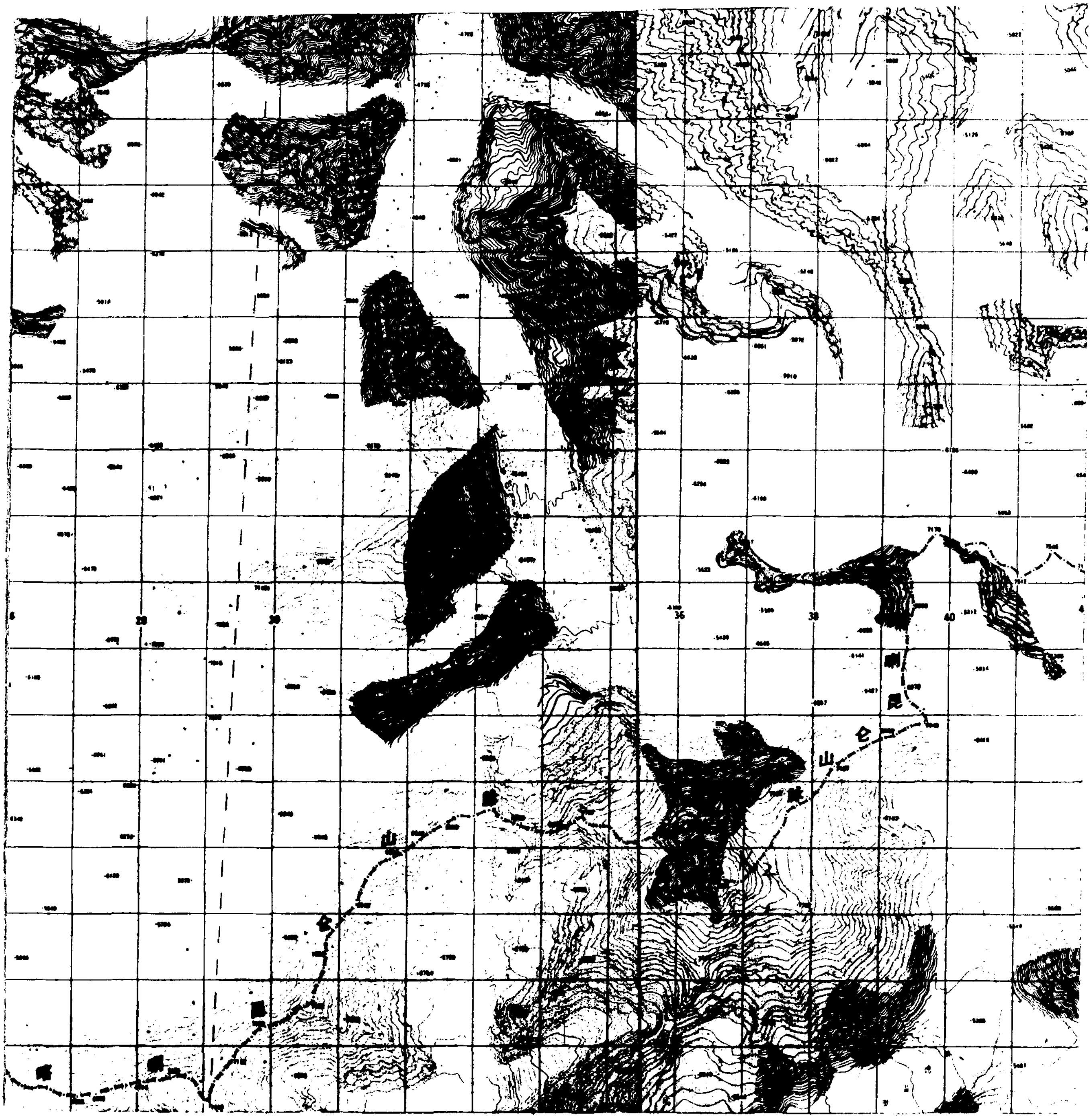

Fig 2 Topographical map of N K2 Glacier and Mount K2 Karakorum at a scale of 1 : 100.000

Mass Volume

Ice mass from the hanging glacier

We assume no entrainmential mass volume at the first distance on the track and the loose ice mass volume being equal to the triangle-shape channel volume on the photo. We can calculate the volume of the channel from the map at a scale of 1:50.000 as 2×10^5 m^3. Thus, the loose ice volume is also 2×10^5 m^3, but the density of the loose ice mass may be 200 kg/m^3.

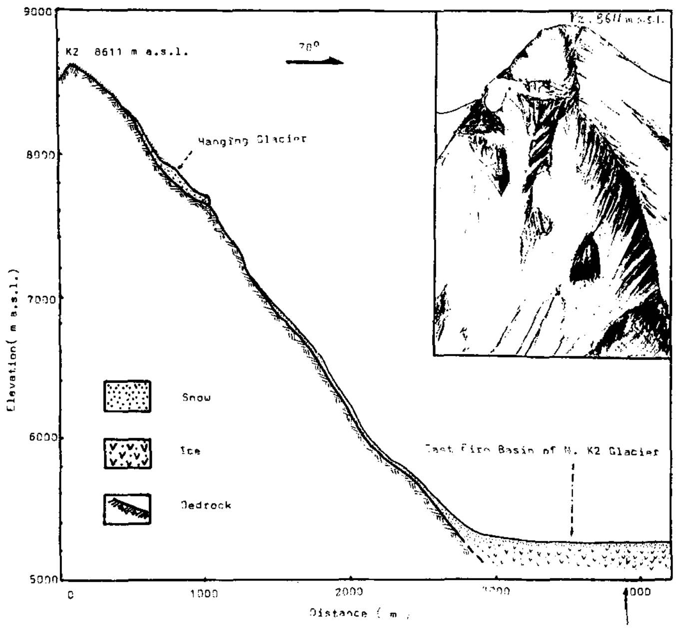

Fig 3 Longitudinal profile of an avalanche path in K2 mount, Karakorum

Moving mass volume

The density profile of a moving avalanche is presently a topic of speculation and, no doubt, varies significantly from case to case. As the avalanche descends the track, it incorporates additional mass into the flow. At the same time, a certain mass with zero momentum will drop out of the flow into the track. The track is covered with snow to appreciable depth, including either newly fallen or wet snow. The surface layer is easily entrained into the flow. Thus, the avalanche mass during the flow is rarely constant.

We can roughly estimate the volume variety of the avalanche from photos at different time or distance. During the first distance of 1000 m the volume increases from 2×10^5 m^3 to 10^6 m^3 but the density is very low ($\rho <$ 100 kg/m^3). During the second distance is approximately 1200 m, the volume amounts to 10^7 m^3 and the avalanche is transported almost into a dust cloud.

Maximum Velocitv

Theoretical formula (Perla, R. I. 1981)

Theoretically, an avalanche accelerates as single, unified mass of snow. On a slope inclining Θ and an avalanche mass M experience tells of a gravitational component mg sin Θ. As shown in Fig 1, the forces resisting acceleration can be lumped into three categories: friction underneath the avalanche, air drug at the front and upper boundaries, and plowing at the advancing tip and the bottom surface. These resistant forces are no doubt a complex function of velocity.

Assume that friction is proportional to the component of force normal to the bed (mg cos Θ) and let μ be the coefficient of friction. We have, thus, the difference between the accelerating and frictional forces mα, where α is

$$\alpha = g \sin\Theta - \mu g \cos\Theta \qquad (1)$$

From hydrodynamics, the air drag force along the front and upper boundaries is assumed to be proportional to v^2 according to the formula

$$\text{air drag} = 1/2\ C_0 A \rho_a\ v^2 \qquad (2)$$

where C_0 is a drag coefficient dependent on the Reynold number and the avalanche shape, A is the area, over which the air drag operates, and ρ_0 is the air density, which is about 1 kg/m^3 at higher elevations.

In principle, plowing resistance should have a very strong v^2 dependance, and then we get

$$\text{plowing force} = A\rho\ [\rho + \Delta\rho)/\Delta\rho]\ v^2 \qquad (3)$$

where A is the avalanche area, over which the plowing force operates, ρ the density of the undisturbed top layer of snow, and $\Delta\rho$ is the change of density due to the compressional force of plowing.

Adding Eqs (2) to (3), expressed as βv^2, we get

$$\beta = \tfrac{1}{2} C_0 A\ \rho_\alpha + A_s\ \rho\ [(\rho + \Delta\rho)/\Delta\rho] \qquad (4)$$

These forces control the change of a momentum of the avalanche. The balance, then, is

$$d\ (mv)/dt = m\alpha - \beta v^2 \qquad (5)$$

Using the formula $d/dx(\Delta\rho) = v\ d/dx(\Delta\rho)$, where x is the distance measured along the path, Eq. (5) may be rearranged as

$$mv\ dv/dx = m\alpha - (\beta + dm/dx)\ v^2 \qquad (6)$$

The term dm/dx represents the material included per unit of the path length (units kg/m).

Assuming initial conditions as V = 0 and X = 0, the velocity at Eq.(6) for the upper slope may be expressed as

$$v\ (x)/\sqrt{2x} = f\ (x, \beta, m, dm/dx) \qquad (7)$$

where $\alpha > 0$. If $\beta \neq 0$, entrainment neglected (dm/dx).

$$v\ (x)/\sqrt{2\alpha} = \{(m/2\beta)[1 - \exp\ (-2\beta\ x/m)]\}^{1/2} \qquad (8)$$

The most common case includes both a β term and an entrainment term dm/dx. Thus, more material is included at a constant rate R along the path,

$$m(x) = M_0 + Rx \qquad (9)$$

where M_0 is the initial mass of the avalanche at $X = 0$. The corresponding velocity at Eq. (6) is

$$v(x)/\sqrt{2\alpha} = \left[\frac{(M_0 + R_x)^{Y+1} - M_0^{Y+1}}{(2\beta + 3R)(M_0 + R_x)^Y} \right]^{1/2} \qquad (10)$$

where $Y = (2/R)(\beta + R)$.

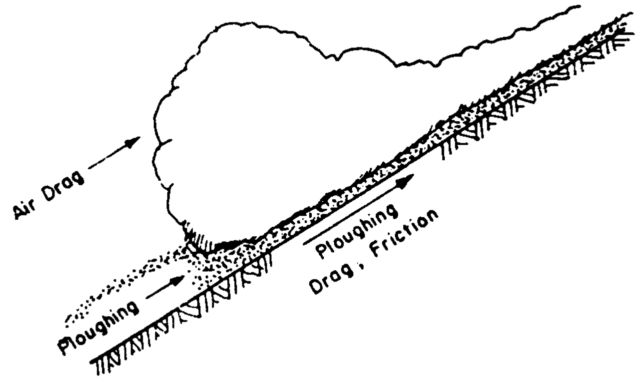

Fig 4 Forces resisting avalanche acceleration

Estimating the K2 Avalanche

We take $C_0 \leq 1$ depending on the shape of the front, the drag area has 10^4 m^2 and is more dependent on the avalanche size according to the photo and map estimations of the avalanche process. Thus, $C_0 A\ \rho_{\alpha_0}/2$ is less than 10^4 kg/m. From the notes of R. I. Perla (Perla, R. I. 1981) we know that with the given avalanche width of the order of 100 m, the plowing contribution could range up to about 10^4. Thus, for β in the case of the K2 avalanche it is equal to 1.4×10^4.

As a result of the avalanche being composed of dry snow and situated on a steep slope, the coefficient of friction was measured and calculated in the case of the K2 avalanche as $\mu = 0.2$. Since the value of R is very difficult to estimate in the field, the upper boundary of the velocity, in terms of the simplest expression, is preferably set at $R = 0$.

Considering the preceding discussion, V(x) on the upper slopes may be estimated by

$$v(x) = \{(mg/\beta)(\sin\Theta - \mu\cos\Theta)[1 - \exp(-2\beta x/m)\}^{1/2} \qquad (11)$$

From the profile of the K2 avalanche path we have an average $\Theta = 50^6$, the initial mass $m = 4 \times 10^7$ kg from above estimated.
Thus,

$$v(x) = \{1.8 \times 10^4\}(1 - \exp(-7 \times 10^{-4}/x)\}^{1/2} \qquad (12)$$

As the avalanche reached the surface of the firn basin, $X = 2760$ m and v (x) max = 124 m/s ($R = 0$).

Runout Distance

When an avalanche enters the top of the runout zone with velocity V_0, $V_0 = V_{max}$, at the beginning, $X = 0, V = V_0$, and the resulting expressions for the distance X, required for an avalanche to come to rest, is as follows:

On the surface of the firn basin, V increases, and m is constant, but β levels are small. Therefore, $m/\beta = \infty$, $R = 0$.
$R = 0$.
Thus,

$$X = V_0^2/2|\alpha| \qquad (13)$$

For the K2 avalanche case, $V_0 = 124$ m/s, $\mu = 0.40$ and $\Theta = 7°35'$.

$$\alpha = g\sin\Theta - \mu g\cos\Theta = -2.6 \text{ and } X_Y = V_0^2/2|\alpha| = 2957 \text{ m}.$$

In the K2 avalanche the width of the E firn basin is only 2000 m. The advancing tip of the avalanche reached the front side, the dust cloud was formed and its height reached 500-600 m up.

Impacting Force

Generally speaking, impacting force means the horizontal impact pressure of moving avalanches, that is the impact pressure P against a plane perpendicular to the direction of the motion. The impact model put forward by M. A. Dolov (Dolov, M. A. 1967) is as follows,

$$P_x = [\rho_2/(\rho_2 - \rho_1)]\ \rho_1 v^2 \qquad (15)$$

where ρ_1 and ρ_2 are densities before and after the impact. But the values of ρ_1 and ρ_2 are difficult to estimate in the field.

R. I. Perla et al. (Perla, R. I.; Beck, T.; Banner, J. 1979) studied the peak impact force. Analysis of their results implies that the peak impact of a discrete snow mass of density ρ_m amounts approximately to

$$(P)_{peak} \approx 1.5\ \rho\ mv^2 \qquad (16)$$

Author	Location	Maximum speed (m/s)	Vertical drop (m)	Path slopes' angle (m^3)	Volume
Cunningham (1889)	Rogers pass, British Columbia	54	500-1000	-	2.0 x 10^5
Briukhanov (1968)	Central Asia, USSR	27	500	45°-20°	1.9 x 10^3
Shen Y. P. (1986)	K2, Karakorum PR China	20.8	300	31°-22° 3.5 x 10^5	
		124	2500	45°-63°	2.0 x 10^5 -10^7

Tab 2 Comparison of avalanches speed and volume

The K2 avalanche consists of particles with $\rho_m = 100$ kg/m^3, moving at $V = 124$ m/s as the avalanche was grounded. Peak pressure could be estimated as 2.3 x 10^6 P.

Discussion and Conclusions

The avalanche of September 16th, 1986, in K2 could have been one of the largest avalanches ever recorded. Dimensions of the path and the vertical descent are large, and the speed of motion reached 124 m/s. Large and great avalanches of this area are rearly seen in the field. Judging by the data obtained, the avalanche was extremely large, its vertical descent being 2500 m, volume 2 x 10^5 m^3 to 10^7 m^3 and the impact pressure 2.3 x 10^6 Pa.

In the K2 area studied, with downcutting valleys and a steep slope, the hanging glacier at 7800 m asl represents the mass source of the avalanche. The avalanche here, therefore, is one of the largest ever described in the world (Tab 2).

Avalanches are dangerous for mountaineering activities. Thus, during two or three days following the storm one had better not cross the E basin at K2. This was the period of potential avalanches.

Acknowledgements

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Characteristics of Glacier Outburst Flood in the Yarkant River, Karakorum Mountains

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Introduction

A catastrophic flood caused by activities of glaciers is called a "glacier outburst flood", or a "glacier outbreak flood" (Rabot, Ch. 1905; Richardson, D. 1968; Vinogradov, Yu. B. 1977). Normal hydrological conditions of the river are disturbed when a glacier outburst flood happens. The flood usually bursts out all of a sudden in summer and autumn with tremendous peak discharge and is initiated by unexpected drainage from supraglacial, englacial or subglacial water bodies as well as from moraine lakes and glacier dammed lakes. In some cases,the flood may be caused by strong glacier ablation during the eruption processes of volcanoes (jökulhlaup). In addition, retreat, advance or surging of glaciers, as well as convergence of complex superglacial streams may also be the factor starting the outburst floods. The study of glacier outburst floods has become a very important research subject in glaciology, especially hydroglaciology, during the past decades. A number of monographical works have been published (edited by Young, J. 1985; Vinogradov, Yu. B. 1977).

Some research was done and several reports were published about the floods in Xinjiang and Tibet (Lai Zuming 1984; Lu Ruren et al. 1986; Xu Daoming 1987). Floods on the N slope of the Karakorum mts. have attracted much attention since the 1920's (Mason, K. 1927; Spoleto, H. R. H. 1930; Desio, A. 1930; Hewitt, K. 1982).

Using the related up-to-date research achievements of scientists from China and other countries, the author analyzed and studied hydrological characteristics and mechanisms of the glacier outburst floods in the Yarkant river.

Hydrometeorological Conditions in the Yarkant River Basin

The basin is situated at the center of Eurasian continent. The climate in the basin is extremely dry, owing to the blockade of the Pamir plateau and the Karakorum mts. The differences of the main meteorological elements on both slopes of the Karakorum mts. reflected clearly the screen effects of the mountains (Tab 1). The area, covered by the glaciers, occupies 11% of the Yarkant basin (above Kagun hydrologic station); glacier meltwater is the major source of the river. Tab 2 shows the main hydrologic features of the river.

The Shaksgam basin, a tributary of great importance in the glacier outburst flood of the Yarkant river, occupies 8223 km^2, in which the area covered by perennial snow and glacier constitutes for 32.4%. The height of snow line is about 5100–5400 m with the glacier tongue at 4200–4700 m. The largest valley glacier in China, the Yengisogat glacier (Crevasse glacier, 42 km long; 380 km^2 in square), is situated in this area. The Shaksgam valley has been disturbed by several large glaciers in the upper reach, and

Stations at north side	long. lat.	alt. (m)	Annual mean precipitation (mm)	Temperature (C) annual mean	Temperature (C) max.	Temperature (C) min.	Stations at south side	long. lat.	alt. (m)	Annual mean precipitation (mm)	Temperature (C) annual mean	Temperature (C) max.	Temperature (C) min.
Kangxiwa	36° 12' N 78° 46' E	3986	36.6	–0.6	24.8	–28.8	Mishar	36° 47' N 74° 46' E	3102	101.7	5.7	32.2	-18.9
Task Kurghan	37° 47' N 76° 13' E	3090	71.1	3.3	29.7	-32.9	Batura	36° 31' N 74° 54' E	2563	126.9	10.0	(34.1)	(-10.9)
Langan	37° 44' N 76° 13' E	1850	96.4	10.2	36.2	-14.0	Gilgit	35° 55' N 74° 20' E	1488	126.9	15.8	45.0	- 9.4
Kagun	37° 59' N 76° 54' E	1420	53.7	11.1	37.6	-20.1	Chiles	37° 25' N 74° 06' E	1180	198.9	19.8	46.7	- 6.7
Yehcheng	38° 16' N 77° 16' E	1231	53.1	11.3	37.9	-22.7							

Tab 1 Contrast of the main meteorological elements in Karakorum mts. (1960–1971)*

*Data of the south flank is taken from Liu Guangyuan 1980

in history has occasionally been blocked by glaciers. At present, the Kyagar and Tram Kangri glaciers are still blocking the Shaksgam valley. The Kyagar glacier dammed lake has been existing for a long time. It is the source region for the glacier outburst flood in the Yarkant river.

Cause Classification of the Flood in the Yarkant River

The annual runoff varies greatly in the Yarkant, 80% of it is concentrated at the flood period (June–September). From July to early September the floods happen frequently. Among them, the glacier outburst floods are particularly destructive due to their special dynamic properties. The oases in the lower reach are usually the disaster areas.

Chief Elements Influencing the Floods and Sources of Floods

1. High-altitude heat conditions. In the Yarkant basin, the area above 5000 m asl, occupies one third of the whole basin, perennial snow and glaciers are mainly concentrated in this area. Temperature is usually taken as the parameter reflecting the integrated heat condition. The higher are the accumulated and maximum temperatures, the greater is the flood volume. Generally, meltwater floods occur frequently in July–August.

2. The catastrophic floods result from the abrupt outburst or drainage of a glacier dammed lake, supraglacial lakes and englacial water bodies. The Karakorum mountains is an area where large glaciers are concentrated; it is also an area with largest scale glacier outburst floods.

Tab 2 Hydrologic characteristics of Kagun station in the Yarkant river

Area of the km^2	Annual mean (m^3/s)	Mean runoff depth (mm)	Mean runoff mean (10^8 m^3)	Annual runoff (10^8 m^3) max tot.	max year	min tot.	min year	Runoff modulus dm^3/s. km^2	Cv
50248	205	133.5	64.6	88.1	1973	44.7	1965	4.08	0.17

3. The flood caused by rainstorm. Precipitation in high mountain areas usually exists in a solid form and has no significant influence on the flood. But summer rainstorms in middle-lower altitude and piedmont may result in torrents and form bigger peak flows, in particular when they converge with ablation flood.

Besides, other physico-geographical factors impose certain influence on the floods at low latitude. Seasonal snow covers and river ice above 3000 m asl melt rapidly in early summer while air temperature sharply increases. Since most areas of the basin are situated in the arid desert zone, the extremely sparse plant cover has little retarding effect on the passing floods. However, in some river valleys (such as the upper reach of the Shaksgam river), large moraines exist, the deposits on the bed are very thick, and many sections of the bed are quite wide, providing ample room for the flood.

According to the above analysis, the floods in the Yarkant river may be divided into three types:

1. Meltwater floods. This kind of floods happens in summer while the ablation is strong due to the rise of air temperature (Fig 1). Generally speaking, the peak flow of such a flood is not very large but its total volume is rather big, its duration is long. Meltwater floods, with apparent daily fluctuation in discharge, usually happen in late June to mid August.

2. Rainstorm floods. At middle-lower altitudes, rainstorms may cause floods. In the Yarkant basin, about 50% of the annual precipitation concentrates in June to August (monsoon), which just coincides with the ablation period. Thus, the rainstorm flood often overlaps the meltwater flood and strengthens its intensity.

3. Glacier outburst floods. They mainly appear on the upper reach of the Shaksgam river. There are several colossal valley glaciers interfered with the Yarkant river for several times during the historic period (Fig 2). The terminus of Gasherbrum glacier in 1985 was laying in a 500 m wide gorge, nearly in the same position as Younghusband saw it in 1889 (Younghusband, F. E 1896).

As early as in June, 1929, A. Desio found that the Gasherbrum glacier had advanced to the cliff on the right slope of the main river valley, the water was forced to flow underneath the glacier and, meanwhile, a deep pond was formed (Desio, A. 1930). In 1953 he found again the Gasherbrûm and Urdok glaciers barring the Shaksgam valley (Desio, A. 1955).

The terminus of the Urdok glacier in 1985 was nearly at the same place as in 1929 (Desio, A. 1930). On an isolated hillock near the glacier snout moraine debris remained. On the right slope (100 m above the valley floor) of the main river valley, moraines were also found, which shows that the glacier had once dammed the river.

A. Desio found that the Tram Kangri glacier dammed the main river valley in 1929 (Desio, A. 1930), 1971 (surveying), 1976 (aerial photo) and 1985 (expedition), but no lake was formed in front of the dam. The bottom of the valley from the glacier dam upwards was composed of sand deposits, and lacustrine terraces were located on both sides (Desio, A. 1930), which means that a lake had once existed there. The drainage form of the lake determined many characteristics of the flood hydrography observed at Kagun.

Besides, the Kyagar glacier dammed the main river valley in 1926 (Mason, K. 1927), 1929 (Desio, A. 1930), 1976 (aerial photo), 1978 (surveying) and July 18, 1978 (satellite image, Hewitt, K. 1982), and a lake was formed. Its maximum volume may amount to 3×10^8 m^3. This lake has

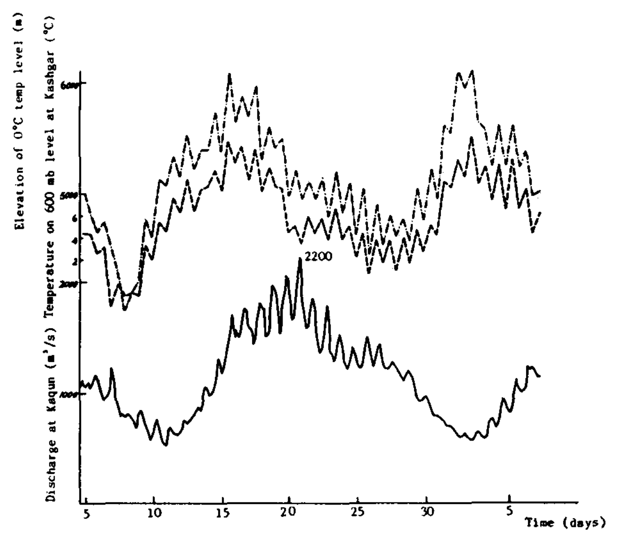
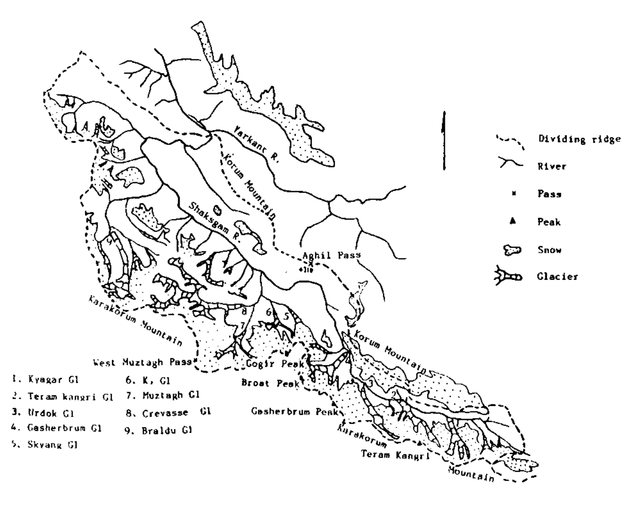


Fig 1 Hydrograph of melt flood at Kagun and high-altitude temperature at Kashgar (July–August, 1793)

Fig 2 Distribution of glacier in Shaksgam basin



No.	Date of peak	Peak discharge (m³/s)	Rising time (hr.)	Total duration (hr.)	Flood volume (10^8 m³)	Qp/Qr	Rising rate (m/h)	Rate of flood travel (Langan-Kaqun) (km/h)
1	29 Aug. 1959	2460	3:30	34:00	0.46	2.88	0.35	12.2
2	4 Sep. 1961	6270	0:30	27:20	1.50	7.78	5.84	14.2
3	24 Jun. 1963	1690	2:00	32:00	0.48	6.04	0.56	11.3
4	16 Sep. 1963	1320	4:30	43:00	0.40	6.35	0.22	12.7
5	6 Sep. 1964	2450	2:30	34:00	0.67	6.12	0.54	11.7
6	21 Aug. 1965	1770	1:45	60:00	0.52	3.82	0.41	12.2
7	29 Jul. 1966	1480	2:35	29:00	0.28	2.20	0.17	12.1
8	10 Aug. 1968	3150	3:12	25:00	0.50	2.29	0.40	
9	2 Aug. 1971	4570	6:00	22:00	0.73	2.43	0.17	16.6
10	16 Jul. 1977	2670	11:00	26:00	0.42	1.92	0.07	15.5
11	6 Sep. 1978	4700	1:30	62:00	1.36	10.93	1.36	12.6
12	30 Aug. 1979	1960	2:12	40:00	0.46	4.59	0.44	11.2
13	21 Oct. 1980	802	1:00	40:00	0.20	4.46	0.78	11.1
14	16 Nov. 1982	856	1:30	22:00	0.19	2.53	0.42	11.1
15	28 Oct. 1983	854						
16	30 Aug. 1984	4570	0:20	42:00	0.84	4.95	5.30	14.6
17	15 Aug. 1986	1980	4:42	22:30	0.51	3.05	0.24	12.5

Tab 3 Characteristics of the glacier outburst floods at Kagun

been existing for a long time. There are lacustrine terraces formed at different time. The drainage was mainly subglacial. The quantity of the water in this dammed lake is crucial to the flood of the lower reach. Fig 3 shows a typical hydrography of a glacier outburst flood in the Yarkant river. Such flood is closely related to the storage and drainage forms of various glacier lakes on the upper reach, but not so closely related to high-altitude temperature.

Hydrologic Characteristics of Glacier Outburst Flood

On the basis of hydrographical data (1954–1986) at Kagun, 17 flood processes showing clear characteristics of outburst were selected (Fig 4, Tab 3), some of which are not pure glacier outburst floods. Hydrographical characteristics of the glacier outburst flood may be described as following.

1. Most of the floods appear during late summer to early autumn, and certain regularities in the time and

Fig 3 Outburst flood hydrograph at Kagun in August–September 1961

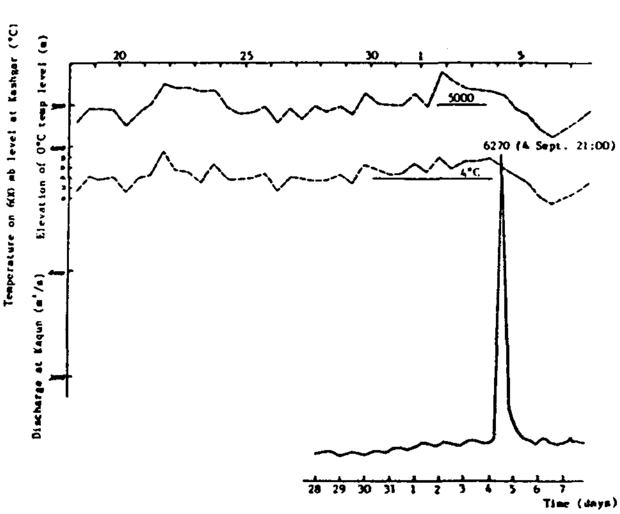
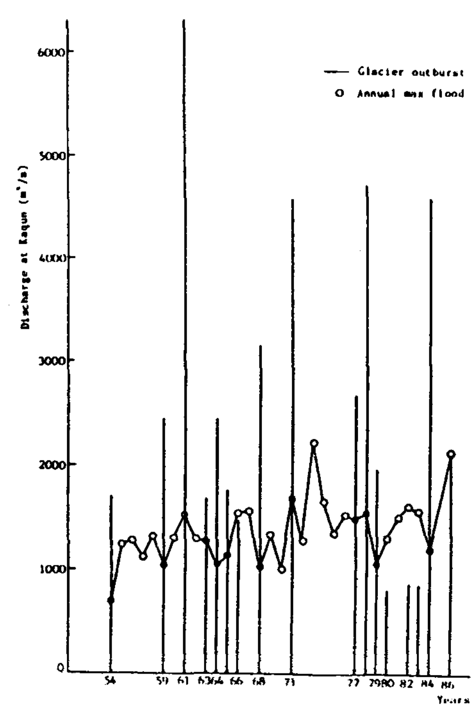


Fig 4 Annual max. melt peak discharge and outburst flood peak



Date	Peak discharge Qp (m^3/s)	Rising rate (m/hr)	Total flood volume (10^8 m^3)	Percentage in annual total volume (%)	Rising duration (hr.)	Flood duration (hr.)	Type of the flood flood
4 Sep. 1961	6270	5.84	1.5	1.8	0.5	7.3	Glacier outburst floot
21 Jul. 1973	2220	0.004	14.1	14.1	236	544	meltwater floot

Tab 4 Contrast of two typical floods at Kagun

frequency of their appearance can be distinguished. All of the floods occurred from June to November, 64% of them took place from late August to November. Usually 84.8% of the yearly maximum floods appeared in July and August. After ice and snow melted intensively in summer, due to accumulation of water and rise of water temperature, channels were formed both below and inside the ice which belongs to temperate glaciers. Warm water opened the channel after the melting period as water pressure increased in ice and, therefore, it resulted in subglacial outburst or lateral drainage. The occurrence time of the glacier outburst flood in this area is similar to that in other places in the world.

2. Glacier outburst floods which happen from June to September are generally the maximum floods of the year (Fig 4), their peak discharges are usually 2-4.5 times of that of meltwater floods. The floods which happened from late autumn to early winter (October to November) could still cause heavy catastrophes in the lower reach of the valley, although their peak discharges are not very high.

3. Contrast of a glacier outburst flood and a meltwater flood

(I) The peak discharge of the glacier outburst flood is often much higher than that of the meltwater flood, but the relationship of the total flood volume is just the opposite. Tab 4 shows the contrast of a typical glacier outburst flood and a typical meltwater flood.

(II) The glacier outburst flood rises and falls steeply. Its rising duration is usually from one to three hours, but sometimes is as short as 20 minutes. The total flood duration is usually from

20 to 40 hours. In contrast, the meltwater flood rises and falls slowly, its rising duration is usually longer than one day, its total flood duration gets to tens of days.

(III) A clear daily variation of the meltwater flood is observed (Fig 1). On the gauge observed at Kagun the daily cycle of rise and fall could be seen, the peak usually appeared in 2 to 6 p.m. every day. Nevertheless, the appearance of the glacier outburst flood peak is irregular and, moreover, its appearance often spoils the regularity of the melt flood peak.

(IV) While the glacier outburst floods appear in the ablation period, they often overlap the meltwater floods. The discharge when rising is relatively big (over 1000 m^3/s), the peak discharge is only one to two times more and the flood duration is a little longer than that of a pure glacier outburst flood.

(V) Statistical analyses of the floods at Kagun are shown in Tab 5. The statistical analyses are made for the contrast. As the glacier outburst flood adds to the statistical analysis of the annual maximum peak discharge, not only the mean value but also the coefficient of variation (Cv) and the coefficient of skew (Cs) greatly increases.

4. Contrast of glacier outburst floods with rainstorm floods. At middle-lower altitude (1300-3800 m asl), 75% of the annual precipitation falls from May to September, and rainstorms happen mainly from June to August, just in the ablation period, thus rainstorm floods often overlap the meltwater floods. The rainstorms are limited in the area,

Tab 5 Statistical characteristics of floods and runoff at Kagun

Item	Mean value (m^3/s)	Coefficient of (Cv)	Coefficient of (Cs)	Statistical time
Annual mean discharge	205	0.17	3 Cv	1984-1986
Annual max. peak discharge	2010	0.60	5 Cv	1954-1986
Annual max peak discharge of meltwater flood	1388	0.17	3 Cv	1954-1986

Name of the glacier dams	Glacier area (km^2)	Glacier lenth (km)	Distance from Kaqun (km)	Altitude of the dam (m, asl)	Height of the dam (m)	Width of the dam (m)	Historical maximum capacity (10^8 m^3)	Condition of the lake	From of drainage
Kyagar	105.6	20.8	517.2	4760	90	1500	3.23	perennial storage and drainage	subglacial drainage
Iram Kangri	124.5	28.0	499.2	4520	60	300	1.92	transitory stroage and drainage	marginal and sub-glacial drainage

Tab 6 Characters of glacier dammed lake at the headwater of the Shaksgam river

this is why their peak discharges can't be very high. Although one can see clearly the overlap of rainstorm flood on the gauge at Kagun, it is very difficult to separate the rainstorm flood from the other type of flood.

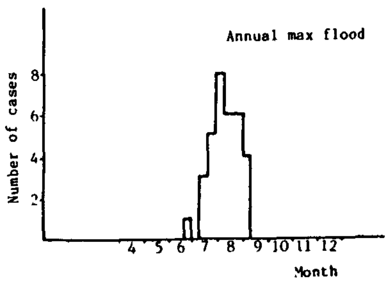
5. Contrast of the glacier dammed lake outburst floods to the moraine lake outburst floods. Moraine lake is surrounded by moraine dams which are left behind after quick retreat of glacier tongue. The flood process of moraine lake is similar to that of a common rockfall dam. The hydrography of moraine lake outburst flood exhibits more characteristics of "outburst", that is, its flood duration is shorter, the rise and fall are steeper.

6. Contrast of supraglacial drainage and subglacial drainage in glacier dammed lakes.

The Meicibahei glacier dammed lake (in the USSR) at the headwaters of Kunmalike river in Xinjiang is a typical glacier dammed lake with subglacial drainage. The maximum length of the lake is 4 km, the width is 1 km and the volume is 2×10^8 m^3. The lake bursts in early September nearly every year. The length of subglacial drainage channel is 14 km (Golubev, G.N. 1976). The most important hydrographic characteristics is that the flood duration is very long, usually several days or several weeks, and, furthermore, the fall is steeper than the rise. The hydrography of the upper reach and the lower reach are quite similar. Field investigation revealed that the drainage was caused by floating up of the damming glacier. The location of subglacial drainage channels can be established by the shape of the dam, distribution of faults and crevasses. As summer approaches, water temperature rises (especially while water from the ambient barren slope flows in), the deformation of ice increases, the lake begins to leak through the englacial crevasses or channels, whereby the channels are further enlarged by heat energy and potential energy of the lake water. Even if floating up of the glacier dam is not continued, it can,t dam up water from draining downstream through the channel. Such drainage mechanism determines characteristics of the

Tab 7 Development of the outburst flood in August 1986 in the Yarkand river

Location	Distance from river source (km)	Altitude (m asl)	Peak discharge (m^3/s)	Time of peak	Rise to peak (hr.)	Duration of flood (hr.)	Rate of travel (km/h)	Heigth of water level rise (m)	note
Kyagar tongue	31.2	4670							
Tram Kangri tongue	46.7	4520	2150*						*after Heab-erli (1983)
21 km downstream from Suhong shoal	119	3840	3100*						*flood survey
langran	430	1980	2130	17:24, 14 Aug.	1.3	18.0		2.01	
Kaqun	546	1320	1980	2:42, 15 Aug.	4.7	22.5	12.5	1.13	



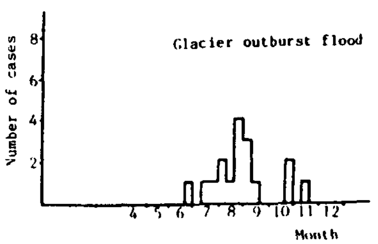


Fig 5 Seasonal distribution of glacier outburst flood and annual max flood at Kagun

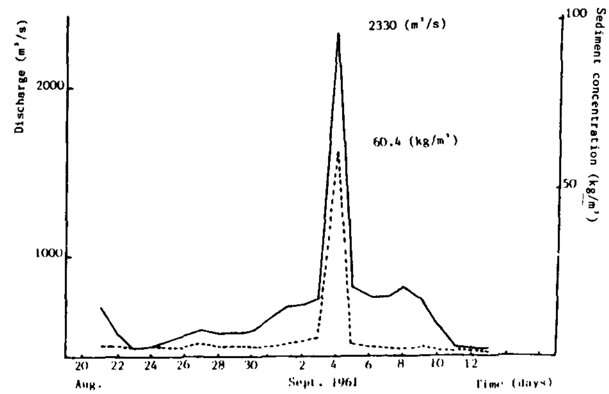


Fig 6 Exceptional sediment concentration and corresponding flood hydrograph at Kagun

flood hydrography. Generally speaking, during the subglacial drainage, channels are enlarged gradually, thus the flood rise is slow (the flood duration is usually several days to several weeks). After the flood peak passage, the flood falls quickly as a result of abrupt closing up of channels or other causes.

Glacier outburst floods caused by supraglacial drainage usually start by overflowing the ice dam. Water above 0 °C can swiftly cut out a channel with its heat energy and potential energy (thermal erosion), until the dam collapses. For instance, the lake on Axel Heiberg Island, Canada, overflowed on July 23, 1973, and 40 hours later a 14 m deep gorge was cut through the ice dam (Maag, H. U. 1969). Another case of supraglacial drainage is the outburst flood in August 1929 by Chong Khumdan glacier dam of the Shyok river at headwaters of the Indus river, S slope of Karakorum mts. The flood began through subglacial tunnels, then carried away the entire ice roof. According to the estimations made, the drain flow amounted for 13.5 x 10^8 m3. Some 3 x 10^5 m^3 of ice were also carried away by the flood. The average discharge in 48 h 200 km downstream of the dam was 7100 m^3/s, and gorge was about 120 m wide and 150 m deep (Gunn, J. P. 1930; Mason, K. et al. 1930).

The characteristics of the flood pattern depend on the drainage forms and features of the glacier dammed lake. There are hydrographic differences between the subglacial drainage and the supraglacial drainage. Therefore, the drainage form of the glacier dammed lake at the headwaters of the Shaksgam river might be the same as that in the upper reach of the Indus river.

At present the Shaksgam valley is dammed by two glaciers (Tab 7). Records show that the storage and drainage of Kyagar glacier dammed lake had happened several times (Hewitt, K. 1982). From this it follows that the glacier outburst flood on September 6, 1978, resulted from this lake. Expeditions since 1926, especially in the past three years, verified that the drainage from the lake is subglacial. Considering the great height of the dam, one can conclude that the drainage was caused by floating up the glacier dam. The Tram Kangri glacier dam lies at 18 km down the Kyagar glacier dam, the terminus of the glacier is 4 km wide, with only 300 m of discontinuous sections blocking the valley. From the expeditions in August 1971 and May 1985 we know these were ice blocks left by outburst floods in 1971 and 1984. A wider valley floor had been scoured out at the terminus after a small flood in the summer of 1987.

In conclusion, the water storage in Kyagar glacier dammed lake plays an important role for the glacier outburst floods at the Yarkant river, while the characteristics and drainage pattern of the Tram Kangri glacier dammed lake determine the hydrographical features of glacier outburst floods at Kagun.

7. The relationship of peak discharge and total volume may be well expressed by the following equation,

$$Q_m = 1.7\ W_m^{0.97}\ (r = 0.92)$$

where Q_m is the peak discharge (m^3/s), W_m is the total volume (10^6 m^3). The total volume of a big flood approximately equals the maximum volume of the present dammed lake. This is another evidence that the glacier outburst floods in the Yarkant river source from the glacier dammed lakes at the headwaters of the Shaksgam river.

8. Periodicity of the floods. According to the data at Kagun since 1954, a period of about 10 years is observed

Stream (station)	Drainage area (km^2)	Annual mean discharge (m^3/s)	Annual mean sediment discharge (10^8)	Annual mean sediment concent-ration (kg/m^3)	Max. sediment concent-ration (kg/m^3)	Erosion modulus (T/km^2. Yr)	Data source and time
Yellow river (Shan Xian)	687,869	426	15.7	36.9	590	2280	annual mean, Chinese water conservancy society 1983
Indus (Kalaqag)	305,000	34878	6.8	6.18		2230	annual mean, Chinese water conservancy society 1983
Yarkand (Kaqun)	50,248	266	0,61	7.22	60.4	1260	1961 mean, hydrologic yearbook

Tab 8 Multiyear mean sediments in the Yellow river, the Indus river and the Yarkand river in 1961

(Fig 4). That is, the glacier outburst floods were very frequent from 1959 to 1971 and from 1977 to 1986, about once within one to two years, whereas the glacier outburst floods ceased from 1954 to 1958 and from 1972 to 1976. Since 1954, a period of 6 to 10 years in the occurrence of large scale floods (with discharge of over 4500 m^3/s) is observed. The glacier outburst floods in the Yarkant river are closely related to the formation, storage and drainage of the glacier dammed lakes at its headwaters, and formation of the glacier dammed lakes is closely related to the advance of glaciers. Therefore, formation of glacier dams and lakes are related to the Little Ice Age. Water storage in the Kyagar glacier dammed lake was recorded in 1920s (Mason, K. 1929; Desio, A. 1930). But no water was stored in the intervals since 1930s, which might result from the regional general retreat of the glacier (Hewitt, K. 1982). Since the 1960s, glacier outburst floods happened frequently, corresponding to the low temperatures in the 1950s that caused a stop in glaciers retreat, and the lower temperatures that led to the advance of the glaciers (Shi Yafeng et al. 1980).

Both the Kyagar and the Tram Kangri glacier dammed lakes are large lakes. Once the dammed lakes were formed, the drainage depends on the amount of water supply and water temperature. The annual water supply of the lakes varies greatly, and so does water temperature; for example, icebergs in the lake can lower the water temperature significantly. Apart from this, clear traces of the lake shoreline could be observed, which can be formed only while water level lingered at a certain level for a long time. Therefore, it may be convincing that large scale drainage does not happen every year in the Kyagar glacier dammed lake. Water drainage of the Kyagar glacier dammed lake flows into the Tram Kangri glacier dammed lake, water temperature increases during the flow process and, in addition, the ice dam (i e glacier tongue) belongs to the temperate glacier type, its subglacial channels are well developed. Therefore, the Tram Kangri glacier dammed lake drains easily. Meanwhile, the lake terrace of the ice dammed lake at the Tram Kangri is not developed so well as compared to that at Kyagar. This implies that the Tram Kangri lake is a transitory one. The Kyagar glacier dammed lake plays a very important role in large scale floods in the Yarkant river.

In conclusion, the formation and height of the glacier dams reflect the advance or retreat of the glaciers and local climate variations during a long period, while the storage of the glacier dams reflects regional heat and weather conditions. Therefore, we understand the glacier and climate conditions through the formation provided by glacier dammed lakes.

Influence of Glacier Outburst Floods

Influences of glacier outburst floods on both sides of the Karakorum mts. are far beyond that of floods caused by extreme weather conditions. The floods usually reach the regions of hundreds and even thousands of kilometers away. Several reservoirs are located at the lower reach of the Yarkant river. Peak discharge of glacier outburst floods is usually 4 to 30 times of a normal discharge, or more. The floods often bring large quantities of sediments. All these bring about great menace and losses to engineering, traffic installations and human property.

Since 1961 many investigations have been carried out after each of the large scale glacier outburst floods. Tab 7 shows a record of glacier outburst floods happened in August 1986.

In addition, attention should be paid to the geological and geomorphological processes of erosion, transportation and sedimentation. The outburst flood, with great height and unique dynamic properties, is able to transport much more sediments than a common flood. Glacier outburst floods are often accompanied by unusual sediment load. Fig 6 shows the variation of sediment content and corresponding discharge in the Yarkant river. Its maximum daily sediment flow (September 4, 1961) is about 160 times bigger than the annual mean value.

Owing to the tremendous scale of the glacier outburst flood in 1961, the annual sediment discharge of the Yarkant river that year was over two times of the annual mean value and its erosional module was half as big as that of the Yellow river (in Shaan Xian). Tab 9 shows the contrast of the sediments in the Yarkant river, the Indus river and the Yellow river. Sediment discharge of a river is very important for construction of reservoirs and channels, for irrigation and hydro-power stations. Sediment deposit diminishes the capacity of reservoirs or even lead to abandonment of the reservoirs. Meanwhile, the flood from reservoirs, with next to no load, downcuts the river bed so seriously that it makes irrigation channels ineffective. Therefore, the sediment concentration, size and their variations should be considered when constructing reservoirs and channels.

Conclusions

1. The drainage of the Kyagar glacier dammed lake and the Tram Kangri glacier dammed lake at the upper Shaksgam is the main reason for glacier outburst floods in the Yarkant river. The Kyagar glacier dammed lake is characterized by subglacial drainage, while the Tram Kangri glacier dammed lake by mainly lateral drainage and, secondly, by subglacial drainage.

2. The drainage mechanism of the Tram Kangri ice dam determines the main characteristics of flood hydrography of the Kagun station, while the Kyagar glacier dammed lake plays an important role in the formation of floods.

3. Glacier outburst floods in the Yarkant river are characterized mainly by high peak discharge, big rising rate, small total volume and short duration. The floods happen mostly from late summer to early autumn. A period of 6 to 10 years in occurrence of large scale glacier outburst floods exist. The periodicity depends mainly on large scale drainage in the Kyagar ice-dammed lake.

4. Formation and dimensions of glacier dams at the upper Shaksgam were determined by long-term variations of the regional climate, whereas the changes of storage capacity in the lake reflect cold and warm changes of alpine region.

Therefore, frequent glacier outburst floods indicate glacier advance and climatic variations.

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Zonation of Flora and Vegetation of the Northern Declivity of the Karakoram/Kunlun Mountains (SW Xinjiang China)

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ABSTRACT: Botanical results of the "Sino-German Joint Expedition to K2, 1986" are presented with remarks on vegetation of SW Kashgaria, the W Kunlun Shan and the N declivity of the central Karakoram mountains. The vertical and horizontal zonation of the vegetation and flora of a cross-section of the Karakoram/Kunlun N declivity from the edge of the Tarim basin to the summit-pyramid of K2 is outlined. The transect covers altitudes between c. 1300 and 5200 m. Altitudinal vegetation belts distinguished along the transect, their extension, and characteristic species are:

I	Colline belt	1300–2100 m	*Zygophyllum xanthoxylon*
II	Montane belt	2100–3700 m	*Sympegma regelii*
III	Subalpine belt	3000–4400 m	*Krascheninnikovia ceratoides*
IV	Alpine belt	4200–4900 m	*Ajania tibetica*
V	Subnivale belt	4800–5200 m	*Sibbaldia tetrandra*

An annotated list of 301 species collected (1 Charophyta, 2 Pteridophyta, 6 Gymnospermae, 292 Angiospermae) is given. Floristical and vegetation features of the Karakoram/Kunlun N declivity are discussed in connection with environmental factors and their variation, and in relation to pleistocene glaciation.

Introduction

The N Declivity of the Karakoram/Kunlun Shan mountain system, from the world's second highest peak K2 (Mt. Godwin-Austen, Chogori, Qogir Feng, 8611 m), down to the edge of the central asiatic Tarim basin (below the altitude of 2000 m) comes off at a distance of only c. 200 km. Phytogeographically, this section of High Asia, which connects the Pamirs with Tibet can be considered a "key position" due to its central continental situation and its enormous relief energy. Bordering to species-rich and very different floristical regions, the area is inhospital to most life forms. But a peculiar and ecologically highly adaptable flora, though only poor in species, was to be expected along steep gradients in the environment and under generally dry-cold climate conditions associated with glacial activity. However, the flora of the central N slope of the Karakoram mountains between the Kunjerab- and the Karakoram passes remained almost unknown up to now.

During the "3rd Sino-German Joint Expedition" from August 15 to November 2, 1986, the author had the opportunity to carry out floristical and phytoecological investigations in the Karakoram/Kunlun N declivity and in the adjacent lowland of the Tarim basin. Some results of this expedition shall be summarized here. The present paper deals only with the collection of Charophyta, Pteridophyta, and Spermatophyta made by the German expedition party, mainly by the author and enriched somewhat by J. P. Jacobsen and K. Lechner. The full set of this, totalling about 900 numbers of 301 species, is stored in the Herbarium of Göttingen University (GOET).

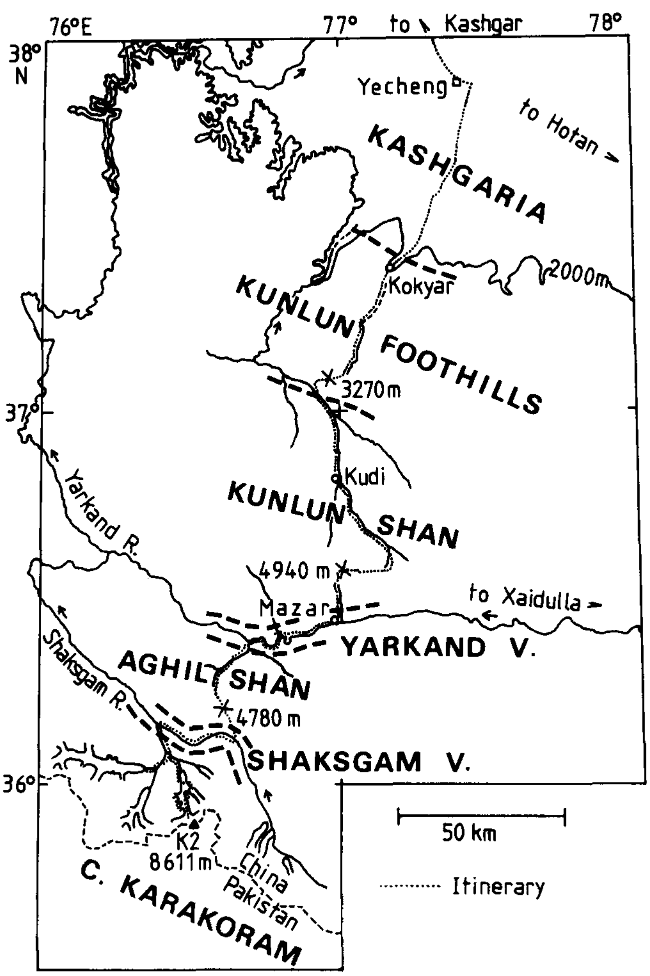
The Expedition Area

The path of the 1986 expedition (Fig 1) can be thought of as a cross-section or transect of the Karakoram/Kunlun N declivity (= KKND, Fig 2) from the periphery (Tarim basin, Kashgarian mountains, Kunlun Shan) to the centre of the mountain system (Aghil Shan, central Karakoram, K2-N-slope).

The transect generally runs in a SSW direction, from N 37° 53' E 77° 25' (Yecheng) to N 35° 52' E 76° 30' (K2). Kashgar (N 39° 28' E 75° 59'), lying to the NW, and the E-W-running intramontane valley stretches of the Yarkand (N 36° 26' E 77° 00' – N 36° 23' E 76° 41') and Shaksgam rivers (N 36° 07' E 76° 39' – N 36° 09' E 76° 25') were included in the area of investigation. Thus, the transect covers altitudes between 1280 m (Kashgar) or 1400 m (Yecheng), and 5060 m (highest directly-investigated locality with plants) or 5200 m (highest location where plants have been seen), close to the north-wall of the ice-covered summit-pyramid of K2.

A geographical division of the transect used for the recording of plant species, is given in Tab 1.

Fig 1 Itinerary of the expedition and geographic-floristical division of the transect



Previous Botanical Investigations

Logistically, the N slope of the Karakoram mountains was almost inaccessible for a long time. Although the famous botanist T. Thomson was the first European to reach the Karakoram Pass in as early as 1847, the area to the N and to the NW subsequently has been entered only by a few botanical expeditions: The Schlagintweit-brothers 1856, Henderson and Cayley 1870, Dutreuil de Rhins and Grenard 1892, Nowitzky 1898, Dainelli and Marinelli 1914, and Clifford 1926.

"La flora del Caracorùm" (Pampanini 1930) is the only comprehensive study of the flora of the area and records some 200 species of higher plants from the N slope of Karakoram ("versante settentrionale"), by far the largest subarea of this flora. Unfortunately, many of the plants cited cannot, without a doubt, be identified according to recent taxonomic concepts. Furthermore, the herbarium material concerned often either does not refer clearly to the N slope of Karakoram or only to marginal areas. Our expedition in 1986 was apparently the first botanical investigation of the central N slope of Karakoram.

On the other hand, the S slope of the Karakoram mountains can be considered fairly well-known today, as several expeditions have worked there. Recent contributions to the flora have been given by Gilli (1957), Kitamura (1964) and, vegetation included, by Hartmann (1966, 1968, 1972, 1984).

There is very little information in literature relating to the flora of Kunlun Shan and the Tarim basin. The first extensive description including a species list was gathered from a journey across the Karakoram pass and the Kunlun Shan to Kashgaria and was published by Henderson & Hume (1873). Another detailed account from a similar route, also E of our expedition area, is given by Schmid in Bosshard (1932). Further important data from the E Pamirs, the W Kunlun Shan, and N Tibet can be found in Ostenfeld in Hedin (1922). Hemsley (1894) and Hemsley's "Flora of Tibet or High Asia" (1902) summarized early botanical knowledge of the vast high plateau adjacent to the SE.

Climate

Physical factors are, to a high degree, varied over the KKND because of extreme differences in altitude, exposition, and geomorphological structure.

The climate generally is strongly continental and extremely arid. Only in the highest altitudes can cold subhumid conditions be expected. The climate diagrams of Kashgar (Western Tarim basin) and Geer (W Tibet), given as examples for "temperate deserts" and "cold mountain deserts" by Song Yongchang (1983), may provide us with a framework for much of our area (Tab 2). However, the extremely low amount of precipitation (c. 60 mm at the altitude of 4300 m annually!) is not representative of the highest elevations, where there are

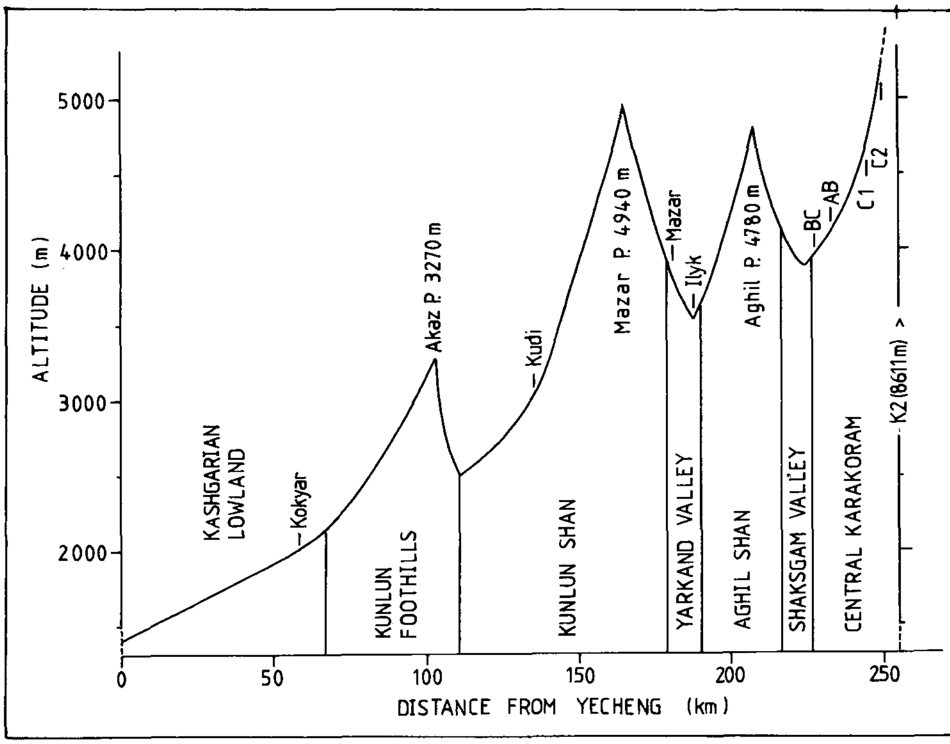


Fig 2
Schematized cross-section (NNE-SSW) of the KKND along the way of the expedition from Yecheng to K2 (pass altitudes are drawn as peaks, latitudinal valley stretches are neglected), geographic-floristical division of the area and important localities (abbreviations: BC = Basecamp, Sughet Jangal 3930 m; AB = Advanced Basecamp, snout of K2-N-Glacier 4120 m; C1 = Camp 1, confluence of Skyang Kangri- and K2-N-Glaciers 4630 m; C2 = Camp 2, medial moraine of upper K2-N-Glacier 5140 m).

no permanent weather stations (cfr. Hartmann 1966; Miehe 1987). A rapid increase of humidity is obvious above the altitude of c. 4400 m in the central N slope of Karakoram.

The high amount of radiation causes extreme annual, diurnal and exposition-governed temperature changes. We found temperatures at the surface of the soil varying daily at least between −2.7 °C (1986-10-07, 06.00 h) and +55.5 °C (13.00 h) in a subalpine *Krascheninnikovia ceratoides – Ephedra intermedia* desert at 3950 m (central Karakoram N slope, Muztagh valley). Those of high alpine *Carex haematostoma – Oxytropis chiliophylla* turf at 4750 m (K2-N-slope) ranged between c. −4 °C (1986-09-21, 06.00 h) and +32.5 °C (13.00 h). In the latter locality, a "thermic mosaic" was observed with persistent frost lenses beneath dry soil that heated rapidly in sunshine.

Aspect and exposition are important factors which regulate evaporation. The N slopes of Kunlun Shan and Aghil Shan are moister and hold a much more varied vegetation than the S slopes. Not a single species was found growing on a S slope exclusively. Lithophytic lichens are almost entirely confined to N-facing rocks of the alpine and subnivale belts where they can reach high species diversities. It is beyond the scope of this article to discuss microclimatical features of the area, but these factors control the altitudinal (and latitudinal) distribution of vegetation types and plant species. Breckle (1973) gives some examples from the neighbouring Hindu Kush mountains.

Geology and Pedology

Comparing geological features and vegetation cover is difficult since there are several interfereing factors which cannot be separated along a single transect. Furthermore, the surface in the KKND may be either very uniform over large areas (loess, glaciofluvial terraces, moraines), or very different in closely neighbouring places (scree fans from opposite flanks). We acknowledge a geological map made by Xu Daoming (personal communication 1987). According to this and other observations made during the journey, only a few factors relevant to vegetation may be summarized.

The principal mountain ranges (Kunlun Shan, Aghil Shan, central Karakoram) contain large plutonic, mainly granite outcrops. Sediments of the ancient Tethys from almost all geological epoches and metamorphites are equally and widely distributed. Slightly metamorphized sediments are even preserved in the innermost mountain range. Large outcrops of siliceous slates in the Kunlun Shan and Yarkand valley (mainly Permian) and in the Aghil Shan (Carboniferous) often make unstable scree slopes. Locally, as by the main fault line between the Kunlun and the Karakoram mountains (Aghil Gorge, c. 3880 m), hard bedrock of quarzite and other

Region (from N to S)	Altitude (m)	Investigation dates 1986	c.% of flora
Kashgarian lowland	1280–2150	15.-18.8., 29.10.-2.11.	30
Kunlun foothills (Kashg. mountains)	2150–3300	18.8., 29.10.	30
Kunlun Shan (main ridge)	3000–4950	18.-20.8., 22.8., 27.-29.10.	50
Yarkand valley	3520–3900	20.-28.8., 23.-27.10.	90
Aghil Shan (N Karakoram)	3550–4830	28.-30.8., 20.-23.10.	70
Shaksgam valley	3870–4100	30.8.-1.9., 19.-20.10.	80
Central Karakoram (main ridge)	3870–5200	1.9.-19.10.	90

Tab 1
Regions/transect sections, altitudinal extension, dates of investigation and estimated degree of completeness of the registered flora.

metamorphites provide better conditions for a richer flora. The summit-pyramid of K2 itself (above the upper limit of vegetation) consists of an extremely hard and heavy, fine-grained striate gneiss.

Limestone is especially apparent in the Aghil Shan, where there are calcareous outcrops ranging from Carboniferous to Jurassic, towered by huge dolomit cliffs. These form the complete mountain range west of the Aghil Pass of more than 2 km in height. This special geological situation (i.e. the better water supply on the foot of these cliffs) might be responsible for a comparatively rich flora noted on the N side of Aghil pass. Smaller calcareous outcrops in the subalpine belt of the Shaksgam and Muztagh valleys (mainly Carboniferous) and other palaeozoic limestone areas of the Kunlun foothills apparently have no special floras.

Extensive loess accumulations almost cover the Kunlun-foothills totally, and are to a lesser extent also distributed in the N slope of Kunlun Shan up to 4400 m. South of the Kunlun Shan main ridge; loess is entirely wanting.

Glacial activity is one of the most important factors determining geomorphology and vegetation of the area. We found a strictly "periglacial flora" only by the K2-North Glacier (4100–5200 m), while actual glaciers of the outer mountain ridges lie much higher. However, extensive pleistocene glaciation must have had dramatic effects on the flora of the Karakoram and certainly is – beneath recent climatic conditions – one of the main reasons for the poverty in species. On the other hand, local glacial water supply makes a relatively rich "arctic-alpine" flora possible.

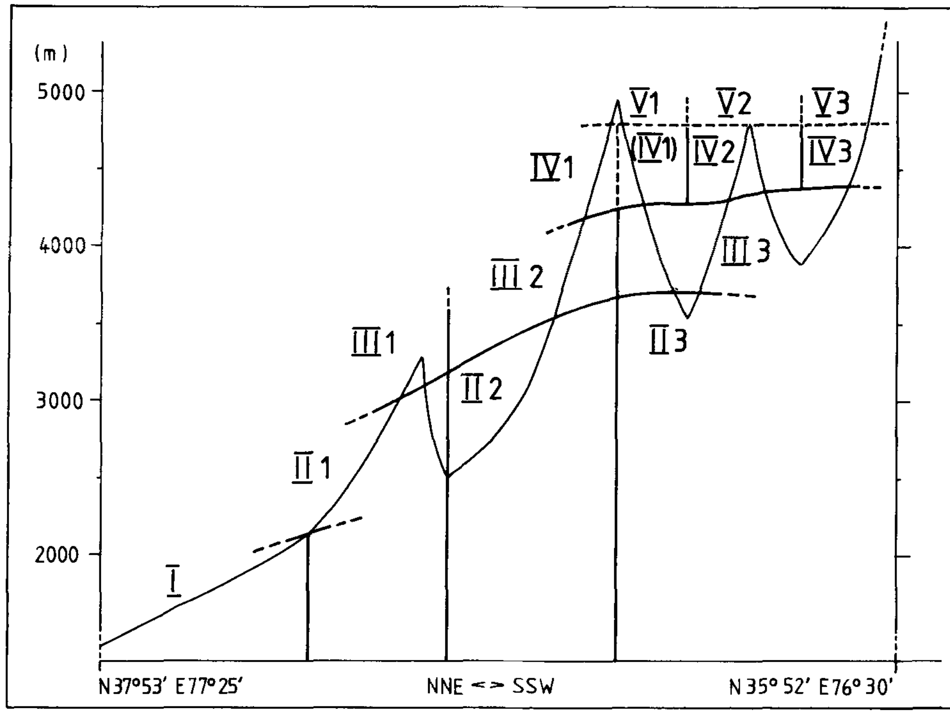
Regarding the wide-spread glacial relief and substrate features, they are often unsuitable for plant growth under the present climatic conditions. Unstable scree slopes, which often almost entirely cover the valley flanks, glaciofluvial deposits and moraines are, where not somewhat stabilized and watered, often devoid of vegetation. Accordingly, extensive steep walls of bedrock along of glacial U-valleys only occasionally have a better developed chasmophytic flora. Usually, vegetation is restricted to narrow strips by the bottom of the walls of rock and slightly inclined, sheltered places of the uppermost scree slopes below them.

Soils generally are poorly developed. Even in the lower altitudes hardly any horizons are to be distinguished. Dominating soil types are Yermosols (desert soils of lower altitudes), Lithosols and Gelosols (high altitudes). Solonchaks locally occur by rivers. Notable accumulations of humus (rarely more than 2-5 cm) were found only in the higher alpine belt under cushions of *Sibbaldia tetrandra* and under spots of alpine turf (*Stipa concinna* p.e.). Fen peat (*Carex, Kobresia*) is restricted to very local situations by springs and flushes.

Locality Coordinates Altitude	Kashgar (Kashi) N 39°28' E 75°59' 1288,7 m	Geer (Gar) N 32°30' E 85°05' 4278,0 m
Precipitation		
mean annual	61,4 mm	60,4 mm
maximum (month)	May	August
Temperature		
mean annual	11,7 °C	0,2 °C
abs. maximum	38,6 °C	25,7 °C
abs. minimum	−24,2 °C	−33,4 °C
Vegetation period	c. 7 months	c. 2 months

Tab 2
Climate dates (from Song Yongchang 1983).

Fig 3
Generalized vertical belts and latitudinal zones of vegetation (cfr. Fig 2; text)



A more or less pronounced salinization is evident almost everywhere below of the alpine belt. Soda efflorescences are frequent up to c. 4200 m. The pH-values (H_2O) of soils under vegetation (alpine turf and subalpine desert) in the central Karakoram N slope (only measured here) are remarkably high and vary between pH 7.5 and 8.4. Alluvial sands (*Myricaria*-thicket) and the water of glacial rivers gave maximum values of pH 8.9 to 9.1.

Hartmann (1968, 1972) should be refered for a detailed analysis of soil chemistry in the S declivity of Karakoram.

Altitudinal Belts of Vegetation and their Zonation

Altitudinal limits of vegetation types are governed by drought and temperature in the KKND. Although trees are almost totally absent from the area (*Populus diversifolia* s.l., *Elaeagnus angustifolia* and *Juniperus turkestanica*, single specimens each), vertical vegetation belts can be clearly defined on floristical grounds and on vegetation physiognomy (cf. Miehe 1988). However, definition, delimitation and altitudinal extension of these may differ considerably from classifications based on geomorphology and from vegetation belts of humid mountains as well. We try to define altitudinal belts by single monitor species, which are easily recognized, wide-spread and frequent in the area, and of clear vertical distribution types. These are *Sympegma regelii* (montane), *Krascheninnikovia ceratoides* (subalpine), *Ajania tibetica* (alpine) and *Sibbaldia tetrandra* (subnivale).

The altitudinal vegetation belts are closely interlaced with different latitudinal zones from the periphery to the central mountain ridges, which complicates the definition of both. A distinct rise of altitudinal limits towards the inner mountain ranges, dependent on relative height of the surface and exposure ("elevation effect") appears in the montane and subalpine belts, less so in the higher ones (Fig 3).

Zhang et al. (1981) gave examples of altitudinal vegetation belts of various regions around the Tibetan plateau. Those summarized by Wang Jinting (1987) for the dry parts of the Tibetan plateau largely correspond to the differentiation of the subalpine and alpine belts of the KKND. However, the borderline between these runs approximately 200 m lower in the central Karakoram N slope than in Tibet. Hou (1984) provided a very detailed vegetation map of China. Due to its scale, of course this can give only a rough approximation on the latitudinal differentiation of the vegetation of our area.

The central Takla Makan desert, which we did not enter properly, might represent the lowest (planare) vegetation belt, or another different latitudinal zone as well. The Takla Makan is the largest desert of China. According to Walter (1974) and Hou (1984), this is a vast dune area almost devoid of vegetation, or with scattered *Tamarix*-scrubs in dune valleys and alluvial woods (*Populus diversifolia* s.l.) on the few rivers that run into the desert.

Colline Belt (Lowland of SW Kashgaria)

The colline belt, which can also be considered a latitudinal zone of its own, comprises the flat to somewhat hilly land on the margin of the Takla Makan desert up to the foot of the bordering mountains. The zonal vegetation of temperate deserts mainly consists of gobis, which are covered with deflation pavements and exceedingly poor in plant species. Where not entirely devoid of plants, Chenopodiaceous and Zygophyllaceous (sub-)shrubs *(Haloxylon ammodendron, Zygophyllum xanthoxylon)* dominate.

Diluvial loess- and sand deserts occur more locally. In reach of surface- or groundwater, the flora is more diverse and has a few succulent summer-therophytes *(Halogeton glomeratus, Bassia dasyphylla, Zygophyllum lehmannianum)* and perennial (herbaceous) plants such as *Launaea* sp., *Calligonum mongolicum* s.l., *Inula ammophila, Alhagi pseudalhagi,* which include a few morphologically distinct endemics *(Apocynum hendersonii, Myricaria pulcherrima). Phragmites australis* is a common indicator of groundwater (Fig 4).

Large oases, of which we saw those of Kashgar-Yengisar and Yarkant-Yecheng at the old Silk Road and Kokyar-Pusha in the lower Kokyar valley, profit by extensive resources of ground- and riverwater which run from the marginal mountains. Inside of the oases fields of cotton, maize and wheat, vineyards, different fruit trees, shelterbelts of pyramid poplars (mainly *Populus alba* s.l.) and urban structures are reminding one of a south-central European or west Asian landscape. Natural alluvial woods are wanting in this densely populated area. Many widely distributed weeds occur around the areas of cultivation and irrigation; only those collected have been included in our species list.

Fig 4 Dune valley c. 20 km S of Yecheng, 1600 m. View NE. This is an unusual feature of rather sheltered situations between extensive gobis of the Kashgarian lowland (colline belt). *Phragmites australis* (foreground) indicates high groundwater level. Herbaceous plants and subshrubs (middleground) mostly are *Launaea* sp. and *Calligonum mongolicum* s.l.; the single tree in the background is the only specimen of *Populus diversifolia* found here. (Photo: Aug. 18, 1986, B. Dickoré)

Montane Belt

As in the preceeding, deserts of Chenopodiaceae and Zygophyllaceae are dominant vegetation types of the montane belt, but the species are entirely different. The Chenopodiaceous subshrub *Sympegma regelii* is the most frequent and characteristic montane species. Most slopes, either on loess of the piedmont and the N slope of Kunlun Shan, or on gravel in the Yarkand valley are dotted with this. The highest locality of *Sympegma* was noted in the Yarkand valley at 3870 m, where it just extends into the N foot of Karakoram (Aghil Shan). *Nitraria schoberi* and *Peganum harmala* of Zygophyllaceae generally are of a similar montane distribution, but they are more restricted to somewhat watered situations in wadis and by rivers.

The upper limit of the montane belt rises conspicuously towards the inner ranges, but obviously most montane species do not reach or cross the high central Shaksgam valley and the Karakoram main ridge. Accordingly, *Sympegma* and *Nitraria*, both wide-spread centralasiatic taxa and frequent N of the Karakoram, are not recorded from the Indian subcontinent. *Nitraria schoberi* has a single population in Baltistan and is supposed to be introduced there by caravans, that crossed the high passes of Karakoram in former times (cfr. Hartmann 1966).

Three horizontal zones may be distinguished within the montane belt:

Montane Kunlun Foothills

The foothills of Kunlun Shan rise rather abruptly above the 2100 m-isohypse. Through the Kokyar valley, at first there is a gentle ascend along with dry rolling moraine hills, which have a thick cover of loess and are dissected by numerous gullies. The disperse and largely uniform loess-desert vegetation covers a relatively high percentage of the surface (5-10 %), but is poor in species. Additional species generally occur in other zones and belts as well *(Stipa splendens, Halogeton arachnoideus, Atriplex sibirica, Orostachys thyrsiflora)*. A few taxa of Irano-Turanian affinities *(Plantago minuta, Reaumuria soongorica)* may be characteristic.

Montane Kunlun Shan N Slope

Beyond the initial foothills there are large rocky outcrops, but loess accumulations are still well distributed. The last village along the transect, Kudi (3000 m), associated with cultivated fields (barley, peas) and timber plantations of shrubby willows (*Salix* cf. *sericocarpa*) and a few poplars (*Populus* sp.) under irrigation, was to be noted here.

The vegetation is highly contracted and almost confined to the valley bottoms (Fig 5). Nevertheless, the flora is relatively rich in species. Common desert plants *(Stipa splendens, Nitraria, Sympegma, Kalidium cuspidatum)* grow on the lower dry slopes. A few other halophytes and many species reminding of the "arctic-alpine" element *(Oxyria digyna, Gentianella* spp., *Primula pamirica, Leontopodium nanum)* were found in meadows *(Leymus secalinus, Poa poophagorum)* by natural watercourses and irrigation channels.

This peculiar composition is strange to an European botanist, but a common feature to the arid mountains of Central Asia (Walter 1974). The boundary between the Mongolian and the Tibetan vegetation provinces (Grubov et al. 1977), or between the regions of "temperate deserts" and "cold mountain deserts" (Song Yongchang 1983) probably fall into this zone.

Montane Yarkand Valley

This differs mainly from the proceeding in the absolute height and the absence of loess beyond the main ridge of Kunlun Shan. Many of the common montane species ascend in the Yarkand Valley to the vicinity of Mazar (3800 m), but do not protrude far into Karakoram. Subalpine species are widely distributed over the whole section of Yarkand under investigation (down to Ilyk, 3520 m). The upper limit of the montane belt is supposed to lie around 3700 m. This however is a rough approximation, and certainly is also subject to great fluctuations in space and time when climatical changes affect this large longitudinal valley.

The lower slopes of the Yarkand valley hold a monotonuous and very loose desert vegetation *(Sympegma, Ephedra intermedia, Krascheninnikovia ceratoides). Myricaria bracteata* – thickets are abundant on broad alluvial plains around Mazar, less so and almost confined to narrow strips by the river downstream, where the Yarkand has cut into a narrow gorge. The large shrubs of *Myricaria elegans* inhabit higher terraces and alluvial fans. Most of this is more characteristic of the subalpine belt (see below). Possible differential montane species are *Clematis tangutica*, the only woody liana of the KKND, and *Hippophae rhamnoides* ssp. *turkestanica*. The latter is strictly confined to river banks and attains a height of 4 m in the lower section of Yarkand (c. 3580 m), while only 30 cm tall shrub of this mark the upper limit of the species at 3780 m.

Several fens and moist grassy places by flushes and springs, usually small and strictly delimitated (Fig 6), proved rather rich in species. Many of these might belong to a wide-spread fen and meadow flora *(Kobresi deasyi, K. royleana, Carex orbicularis, C. microglochin, Blysmus sinocompressus, Eleocharis quinqueflora* ssp. *meridionalis, Primula pamirica, Gentianella vvedenskyi),*

Fig 5 Kunlun Shan N slope, view S from 3020 m, c. 0.5 km S of Kudi upwards the Kudi valley; montane belt. Loess is still well distributed on the valley bottoms and the more gentle slopes of this glacial landscape. The extensive walls of rock at this altitude are almost devoid of plants. The valley bottom has a rich flora in places, consisting of common desert plants (*Stipa splendens:* foreground) and species-rich meadow and turf vegetation by watercourses (*Leymus secalinus* below of an irrigation channel: foreground right).
(Photo: Aug. 18, 1986, B. Dickoré)

Fig 6 Mazar Fen, on the mouth of a lateral valley c. 3 km W of Mazar. View S from 3780 m towards Yarkand valley and Aghil Shan N slope; montane/subalpine belt. This fen is a small (c. 2000 m^2), strictly delimitated patch of vegetation by a spring, which shows a distinct zonation towards the surrounding desert. The central part (1) is a tufted moor of *Kobresia deasyi*, the margin (2) is a species rich fen *(Carex orbicularis, C. melanantha). Myricaria bracteata* – thickets (3) occur on the alluvial gravel plains. The extensive steep rock and scree slopes of the central subalpine belt are pioneered by *Krascheninnikovia ceratoides*, or almost devoid of vegetation.
(Photo: Aug. 25, 1986, B. Dickoré)

Fig 7 Upper Muztagh valley, gully from the N-facing slope c. 2 km below of the tongue of Crevasse glacier view S from 3980 m. The typical (lower) subalpine vegetation of the inner mountain zone consists of c. 60 m high shrub of *Krascheninnikovia ceratoides* (1) and *Ephedra intermedia* (2). Large shrub (c. 2.5 m) of *Myricaria elegans* (3) is confined gullies. The higher slopes hold *Krascheninnikovia ceratoides – Stipa caucasica* ssp. *glareosa* – deserts (4). (Photo: Oct. 14, 1986, B. Dickoré)

which is more or less azonal. Remarkable species seen only on the valley bottom of Yarkand include *Dactylorhiza hatagirea, Potamogeton pectinatus, Polygonum pamiricum, Equisetum ramosissimum* and *Carex melanantha.*

A few abandoned fields at 3710 m are the last remnants of former agriculture in the upper Yarkand valley. However, the valley is an important thoroughfare. The highway Yecheng-Tibet runs from the relais station Mazar up, while a modern road down the valley is again destroyed by violent erosion and rock fall, nevertheless used by caravans. It is therefore not surprising to find a pronounced anthropo-zoogenous flora there. This includes *Cirsium arvense* and *Lactuca tatarica*, frequently growing by the river and not necessarily adventive, and a number of annual species found by caravan resting places *(Chenopodium glaucum, Ch. schraderianum, Ch. prostratum, Senecio krascheninnikovii, Zygophyllum lehmannianum,* and others).

Subalpine Belt

Krascheninnikovia ceratoides, another Chenopodiaceous shrub, which in the KKND attains a maximum height of 1 m, often less, characterizes the subalpine belt. The upper limit of this does not show a large elevation effect (Kunlun N slope 4200, Karakoram N slope 4400 m), but is strongly depending on exposition.

Thus determined and deviating from conditions of humid mountains, the potential timberline runs within of the subalpine belt, not on its upper margin. On the piedmont slope, a shrub belt of *Juniperus pseudosabina* which does not descend below of 3200 m, may give an idea of the drought-controlled lower limit for zonal tree growth. Accordingly, the only tree of *Juniperus turkestanica*, found in the N slope of central Karakoram standing at 3980 m, might well reflect the combined effects of coldness and drought, which in a way reduced the forest belt to a single point.

Some important subalpine shrub species *(Ephedra intermedia, Myricaria elegans, Myricaria bracteata)* normally do not ascend higher than 4100–4200 m, but even this makes no distinct change in vegetation physiognomy towards the alpine belt, which happens still higher (see below). However, a lower subalpine *Krascheninnikovia ceratoides – Ephedra intermedia* belt of the inner mountain region can be distinguished. This generally is exceedingly barren and over vast areas these two species are the only plants to be found.

There is a considerable diversity between the subalpine belts of the outer slopes, while the inner zone is very uniform:

Subalpine Kunlun Foothills

Rich shrub steppes which cover as much as 40 % and more of the surface occur around the height of Akaz pass (3270 m). Shrubby species of loess slopes include *Krascheninnikovia ceratoides, Kalidium cuspidatum, Reaumuria soongorica, Caragana polourensis; Juniperus pseudosabina* grows by rocky outcrops. Thickly loess-incrusted cushions *(Androsace squarrosula, Acantholimon diapensioides)* are apparent on the more gentle slopes and in sheltered depressions. These indicate recently progressing loess accumulation in the summit-region of the Kunlun foothills.

Subalpine Kunlun Shan N Slope

Desert communities of strongly grazed, cushion-like *Krascheninnikovia ceratoides* (not to be confused with *K. compacta*!) colonize dry loess and gravel slopes and are generally very loose and poor in species. Close to streams, this is interspersed with rich fen and turf spots, which have some floristic elements of the N central-asiatic mountains *(Thermopsis alpina, Braya rosea, Stellaria irrigua).*

Subalpine Central Zone (Yarkand, Aghil Shan, Shaksgam, Central Karakoram)

The central subalpine belt largely consists of monotonous shrub deserts with a vegetation cover rarely exceeding 15 % and average species numbers only around 4-6/100 m^2. Typical species are: *Krascheninnikovia ceratoides, Ajania fruticulosa, Stipa caucasica* ssp.

Fig 8 Muztagh valley and The Crown Massif. View W from 4400 m on the W-facing slope of the ridge between Muztagh- and K2-N-valleys; subalpine and higher belts. The almost inaccessible and unexplored compact granite massif of The Crown (7265 m) may prove an interesting former Nunatak system. The pleistocene maximum extent of the Muztagh glacier is indicated by the upper edge of scree-fans and polished rocks (—) which runs around the same height as the present borderline between subalpine and alpine vegetation on the opposite flank (c. 4400 m). The almost flat, gravelly bottom of the Muztagh valley is c. 2 km broad, descends very slightly from the tongues of Crevasse glacier (4000 m: background left) and Sarpo Laggo glacier (outside left) to the Shaksgam valley (3870 m: right; background: Aghil Shan). The valley bottom is almost devoid of vegetation. Only the E side of the valley bottom above the alluvial fan of K2-N-River (middleground right) has a large area of *Myricaria*-thickets (1. dark dots). The Muztagh fen (2) borders a small rivulet. *Salix pycnostachya* occurs from here to K2-Basecamp, situated half way between Muztagh fen and the mouth of K2-N-River.
(Photo: Oct. 9, 1986, B. Dickoré)

glareosa and *Oxytropis microphylla.* A few additional shrubs usually are confined to special situations such as walls of bedrock, boulder-rich slopes, gullies and scree-fans (*Ephedra intermedia, Berberis ulicina, Rhamnus prostrata, Myricaria elegans, Potentilla salesoviana;* Fig 7). Young fluvioglacial terraces and moraines of the K2-N-Valley hold a very loose, but highly characteristic pioneer-association (*Corydalis adiantifolia* s.l., *Crepis flexuosa).*

The gravelly bottoms of the large intramontane valleys are almost devoid of vegetation, or pioneered by single plants of *Arnebia guttata, Elymus nutans, Chamaerhodos sabulosa,* and others. Particularly barren is the c. 800 m broad bottom of the Shaksgam valley. Along the 25 km long valley section crossed, we found only 14 plant species somewhat more regularly. *Myricaria bracteata*-thickets and meadow spots (*Blysmus sinocompressus, Calamagrostis pseudophramites, Leymus secalinus)* only locally occur in sheltered basins less subject to substrate-shift by wind, frost and hydration changes, or flood events. The largest patch of *Myricaria*-thickets (c. 2 km^2) borders the E Muztagh valley above the alluvial fan of the K2-North River (Fig 8; basecamp).

Moors (alkaline fens) are very rare features in the central subalpine belt. Only two examples were found in the upper Shaksgam valley and just S of the basecamp in the Muztagh valley. The Shaksgam moor (c. 4060 m) lies on the margin of the alluvial fan descending from the Aghil pass gully. This is a sharply delimitated rounded patch (c. 1000 m^2) of damp turf (*Carex orbicularis, C.* cf. *pycnostachya, Triglochin maritima)* surrounded by bare ground. The Muztagh moor (called "Sughet Jangal", i. e. wood of willows) is a relatively large (c. 0.05 km^2) oblong patch of rich vegetation associating a spring below of a gully from the ridge between the Muztagh- and K2-N-valleys. This is the only locality seen, where *Salix pycnostachya* occurs. It forms a dense "forest", up to c. 4 m tall and consisting entirely of this species. The zonation along the watered area comprises flushes (*Dilophia salsa),* tufted "Naka" moor (*Kobresia stenocarpa),* species-rich fens (*Carex orbicularis, C. microglochin),* damp sandy (*Puccinellia kashmiriana),* and dry sandy places (*Potentilla virgata),* which form narrow transitional zones to the surrounding desert.

Alpine Belt

A distinct species-change associated with a considerable increase of species-number and percentage of vegetation cover happens on the upper fringe of the subalpine belt. This is most pronounced in the central mountain part, where species composition changes almost totally around 4380 m within c. 20 m of altitude (K2-N-Slope). On the N slopes of Aghil and Kunlun Shan alpine species descend further down and are more intermixed with subalpine desert species.

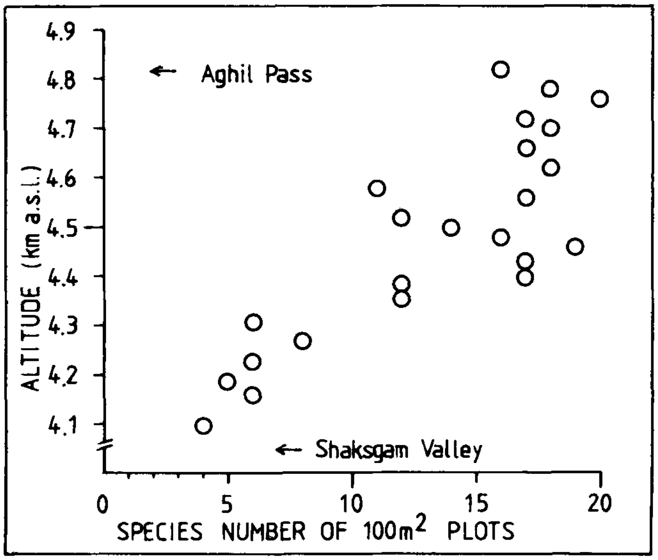


Fig 9 Aghil Shan S slope, dry gully from Aghil pass: Altitude versus species number of randomized 100 m^2 plots (data obtained Oct. 20, 1986). A distinct increase of species number between 4300 and 4400 m marks the border between subalpine and alpine belts. Species number does not distinctly decrease at the highest altitudes, possibly due to the pass situation.

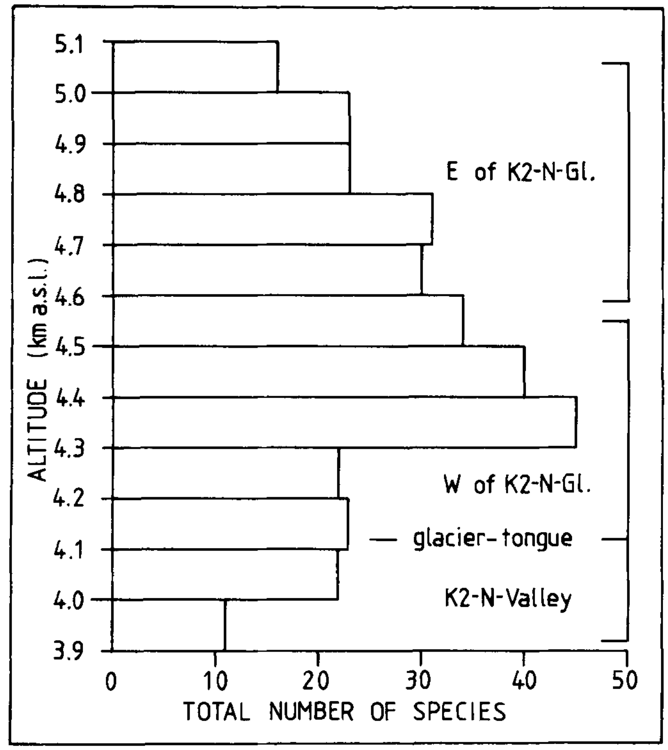


Fig 10 K2-N-Valley, central Karakoram: Total number of species found within 100 m steps of altitude (data obtained Sept. 2 to Oct. 12, 1986). Species diversity reaches a clear maximum in the lower alpine belt. Species number decreases apparently linear at high altitudes. The absolute upper limit of phanerogamic plants can be expected at c. 5500 m.

The species-change on the lower limit of the alpine belt furthermore is associated with replacements within of pairs of closely related species. The most obvious examples of altitudinal vicarious species pairs are (subalpine-alpine species): *Ajania fruticulosa* – *A. tibetica* and *Oxytropis microphylla* – *O.* cf. *chiliophylla*. Other examples, where genetical relationships is less definite, or one of the species is rare, may comprise: *Elymus nutans* – *E. schrenkianus, Krascheninnikovia ceratoides* – *K. compacta, Lonicera asperifolia* – *L. semenovii, Rheum tibeticum* – *Rh. spiciforme*. Generally, the mutual exclusion of these altitudinal vicariants is much more significant on single slopes than might be expected from our species list, which gives only the total altitudinal range (elevation effect, azonal habitats, swept plants).

Another obvious change between the subalpine and alpine belts is the replacement of the dominating wind-pollinated subalpine desert shrubs by insect-pollinated chamaephytes and hemikryptophytes. Species diversity reaches its maximum in the lower alpine belt (Fig 9, 10). A lot of species seem to be confined to a narrow zone, which is not too dry and not too cold. *Festuca olgae*, distinct from its large tufts forms a (lower alpine) belt on N slopes that may be considered separately. However, the vegetation cover of the alpine belt is by no means continuous, but often disintegrated into isolated patches. The Kunlun S slope between c. 4000 and 4800 m is almost devoid of vegetation.

The alpine vegetation also displays a maximum diversity between each of the mountain ridges:

Alpine Kunlun Shan (N Slope)

There is a rich subalpine-alpine transitional zone (*Krascheninnikovia ceratoides, Festuca olgae, Androsace squarrosula*) on loess-covered slopes of the Kunlun N slope (upper Kudi valley) between 4000 and 4200 m. Continuous vegetation quickly diminishes along a steep rocky gorge higher up, but isolated patches of block scree- and initial turf vegetation proved rich in interesting species. At c. 4380 m, *Poa poophagorum, Koeleria litwinowiana, Rheum spiciforme, Rhodiola himalensis, Leontopodium nanum, Braya pamirica, Pleurospermum lindleyanum, Androsace flavescens, Saussurea gnaphalodes, Gentiana karelinii,* and others were found.

The highest section of the Kudi valley is a c. 10 km long, broad glacial trough. Alpine deserts and loose, but relatively species-rich chamaephyte-associations (*Krascheninnikovia compacta, Dasiphora dryadanthoides, Ajania tibetica, Thermopsis inflata, Parrya exscapa*) dominate around 4600 m. Between 4600-4800 m, there are some larger patches of (high-) alpine turf; but no closer examination could be done here.

Alpine Aghil Shan

Many alpine species descend to the Aghil gorge (c. 3880 m) of the Aghil Shan N slope, where there are shaded bedrock-cliffs, abounding in species *(Artemisia compacta, Lonicera asperifolia, Poa poophagorum, Ajania tibetica, Dasiphora dryadanthoides, Dolomiaea macrocephala)*. The subalpine-alpine transitional flora, species-rich in places, ascends to c. 4200 m. Stable terraces of a broad valley section above the gorge have cushions and spots of dry turf *(Oxytropis ampullata, O. microphylla, Orostachys thyrsiflora, Ephedra gerardiana, Stipa purpurea, Poa poophagorum, Potentilla agrimonioides)*; shrubby species include *Krascheninnikovia ceratoides, Berberis ulicina* and *Lonicera asperifolia*.

At 4150 m, a single stone hut built on a calcareous rock-wall and serving as summer-habitation of a family of Kirghiz herdsmen, marked the last human settlement towards the inner mountain system. *Microula tibetica, Axyris prostrata* and *Chenopodium prostratum* were growing on goatdung. More or less grazed and dwarfed specimens of alpine species found in crevices of limestone rocks include *Viola biflora, Draba altaica* and *Potentilla saundersiana*.

Higher up, the flora of the ascent to Aghil pass, although heavily grazed, proved rich in plant species. It would well repay a closer and more prolonged examination. A diverse but scanty vegetation grows on the more stable calcareous *(Oxytropis ampullata, O. densa, O. pagobia, Astragalus strictus, Tanacetum pyrethroides)* and granite scree slopes *(Potentilla bifurca, Rhodiola fastigiata, Artemisia stricta, Ptilotrichum canescens)*, which alternatively come down from short lateral valleys and rock-walls.

Above of 4500 m and up to the height of Aghil pass (4780 m), the valley broadens to a gently ascending glacial trough. This has an exceptionally rich alpine flora with an almost 100% vegetation cover in places. Species found in loose dry alpine turf include *Stipa concinna, St. purpurea, St. subsessiliflora, Poa poophagorum, Calamagrostis holciformis*. Flushes and watered places on the stream's edge have a dense growth of small turf sedges and grasses *(Carex montis-everestii, C. atrofusca* ssp. *minor, C. pseudofoetida, Poa calliopsis)* and other species *(Polygonum viviparum, Gentiana karelinii, Gentianella azurea, G. pygmaea)*. Tall forbs *(Carex nivalis, Delphinium brunonianum)* are thinly distributed on the Aghil N slope, but there are large patches of tufted "Naka" (frost-broken) moor *(Kobresia deasyi, K. royleana)*.

Higher up, *Primula macrophylla* and *Saxifraga hirculus* are distinctive species of small streams and flushes within of and on the margin of moors. An association of flat cushions, or sort of frost-cracked dry highalpine turf *(Kobresia capillifolia, Oxytropis chionobia, Potentilla pamirica)* grows on relatively stable granite scree slopes with stone-polygons (Fig 11). Both communities, the first resembling those of "snow-valleys", the latter of wind-blown *Elynetea*-communities of the European Alps, we saw only in the upper alpine belt of the Aghil Shan N slope.

The steep, dry S slope of Aghil Shan has a scanty vegetation. Nevertheless, alpine desert-steppes *(Carex stenocarpa, Stipa subsessiliflora, Allium carolinianum, Oxytropis densa, Ajania tibetica)* down to c. 4400 m are relatively rich in species (cf. Fig 9).

Alpine Central Karakoram N Slope

A pronounced species-change and increase of species number happens above of a steep ascent along the lateral moraine W of K2-N-Glacier at c. 4380 m (see above, cf. Fig 10). This generally is similar on the E slope of Muztagh valley, where there is a distinct *Festuca olgae* – belt on more gentle slopes.

The lateral moraine W of K2-N-Glacier broadens above. From c. 4400 to 4500 m, chamaephyte-communities *(Astragalus webbianus, Oxytropis* cf. *chiliophylla, Ephedra monosperma, Pleurospermum govanianum, Ajania tibetica, Rhodiola fastigiata, Poa poophagorum, Elymus schrenkianus)* grow on the boulder-strewn slopes. These are rich in species, but the vegetation cover is not very dense and interrupted by several gullies and rapidly moving rock-streams, which are devoid of vegetation. Tall *Carex nivalis* – meadows (with *Delphinium brunonianum* and various other species) cover relatively large areas. These indicate rather sheltered and moist conditions, but true alpine turf

Fig 11 Aghil Shan, just N of Aghil pass, 4780 m. High alpine turf cracked by frost heaves on slightly inclined NE-facing granite scree slope with *Kobresia capillifolia* (1), *Oxytropis chionobia* (2) and *Potentilla pamirica* (3). (Photo: Aug 30, 1986, B. Dickoré)

Fig 12 W of K2-N-Glacier, 4550 m. Alpine "rock-garden" below of steep E-facing walls of granite bedrock with *Thylacospermum caespitosum* (1), *Dasiphora dryadanthoides* (2), *Oxytropis* cf. *chiliophylla* (3), *Rhodiola fastigiata* (4), *Lonicera semenovii* (5) and *Rheum spiciforme* (6). A recently fallen boulder (centre) caused notable damage on the frost-shattered soil and vegetation. (Photo: Sept. 14, 1986, B. Dickoré)

Fig 13 View SSW from 4580 m over the K2-N-Glacier towards K2 summit (8611 m, in 15 km distance); upper alpine and higher belts. Almost the whole landscape is devoid of vegetation. Only the N slope of the glacier-smoothed foothill of the Nunatak (1) between K2-N-Glacier (middle) and Skyang-Kangri glacier (to the left) has a fairly species-rich high alpine and subnivale vegetation. The highest vegetation spots have been found beyond this, approximately where the projection of the NW-spur of K2 meets the foothill on the photo.

The transgressing monsoon occurred shortly before bad weather with average day temperatures dropping below of 0 °C at the end of the vegetation period. The actual snowline approximately coincides with the absolute upper limit of vegetation.
(Photo: Sept. 8, 1986, B. Dickoré)

(Leontopodium nanum, Lagotis decumbens, Viola kunawurensis) is restricted to very local situations. Between c. 4450 and 4550, vegetation of granite block-scree *(Rheum spiciforme, Lonicera semenovii, Rhodiola fastigiata, Nepeta longibracteata, Cystopteris dickieana)* and chasmophytes of the steep flanks above *(Thylacospermum caespitosum, Saxifraga pulvinaria, Viola biflora, Dolomiaea macrocephala)* become dominant vegetation features. Beautiful small "rock-gardens" below of very steep rock-walls at 4550 m probably are among the highest localities for any plants W of K2-N-Glacier (Fig 12). Higher up on this side of the glacier, the rock-walls are inaccessible, and apparently devoid of vegetation as well.

Large tracts of mobile scree E of the K2-N-Glacier equally are devoid of higher plants and lichens. However, a species-rich flora *(Festuca olgae, Stipa purpurea, St. subsessiliflora, Rhodiola fastigiata, Leontopodium nanum, Dracocephalum heterophyllum, Lonicera semenovii, Dasiphora dryadanthoides)* occurs again on a small isolated patch of alpine turf at the mouth of a lateral gully (4590-4620 m). Higher up along the glacier, there are extensive rock-walls, which have a scattered, but still relatively rich flora. *Thylacosperum caespitosum* is characteristic of sunny rocks, while the other species which forms dense cushions, *Saxifraga pulvinaria*, is strictly confined to N-facing shaded cliffs. Additional species seen between boulders below of the rock-walls include *Oxytropis* cf. *chiliophylla, Nepeta longibracteata* and *Waldheimia tomentosa*. Camp 1 (4630 m) was situated on moraine-gravel just NE of the confluence of the Skyang Kangri- and the K2-N-Glaciers; the only species growing here was *Ajania tibetica*.

S of Camp 1 and across the Skyang Kangri glacier, there is a glacier-smoothed rolling hill. This is part of a Nunatak, completely encircled by glaciers (Fig 13). A spot of dense turf with *Oxytropis* cf. *chiliophylla* on a small rocky plateau c. 50 m above of the K2-N-Glacier (4750 m) may be considered the highest location for alpine vegetation (see below).

Subnivale Belt

The delimitation of the subnivale vegetation belt is difficult, although the species composition is very characteristic. *Sibbaldia tetrandra* and *Saussurea gnaphalodes* are frequent cushion-like species on superficially thawing permafrost slopes of the free gelifluction belt, common to all three major mountain ridges. Usually, plants are confined to slightly inclined (<5°) slopes, whereas only exceptionally any higher plants or lichens can withstand the rapid debris movement of the abundant 35° slopes.

The lower limit of the subnivale belt approximately runs around 4800 m on each N slope of the area, but this largely depends on (micro-) exposition. Characteristic dicotyledonous cushion-like species may descend below of 4500 m and, on the other hand, fairly closed and species-rich (high) alpine turf *(Stipa concinna, Kobresia pusilla)* locally can be found above 5000 m.

The subnivale flora seems to be somewhat different on each mountain ridge, but less so than in the alpine belt. Owing to lack of data and the generally low species numbers on the upper limit of vegetation, the following distinctions must remain tentative:

Subnivale Kunlun Shan

Around the height of Mazar pass (4940 m) seedlings of *Sibbaldia, Saussurea, Silene gonosperma, Draba oreades* and *Lagotis decumbens* locally occur on slightly inclined frost debris slopes.

Subnivale Aghil Shan

Sibbaldia, Saussurea and *Draba oreades* also grow around Aghil pass (4780 m). *Nepeta longibracteata* is another characteristic species found in steep, exposed, dry scree. A variety of (high) alpine species ascend to the height of the pass (see above); higher localities have not been investigated here.

Subnivale Central Karakoram N Slope

There is an area of c. 0.6 sqm and between 4720-5040 m of altitude with high alpine and subnivale vegetation on the N slope of the hill towards K2-N-Glacier (5046 m, 11 km NNW of K2 summit) of the Nunatak E of K2-N- and S of Skyang Kangri glacier. Although close to the upper limit of vegetation, the plant cover is rather dense. 37 species of phanerogams have been found here, including 9 species not found elsewhere along the transect (*Oxytropis* sp., *Carex haematostoma, Draba winterbottomii, Lagotis globosa, Potentilla gelida, Saxifraga oppositifolia, Sibbaldia olgae, Stellaria* cf. *decumbens* and *Waldheimia tridactylites*). The lichen and moss flora of the Nunatak seems to be rich too. *Sibbaldia tetrandra* and *Saussurea gnaphalodes* are common on free gelifluction slopes. *Sibbaldia* was not found elsewhere lower down in the K2-N-Valley. A very steep (35°) scree-slope held an exceptionally rich version of this association, where many species apparently slided down from higher slopes. Highalpine or subnivale turf spots with a vegetation cover up to 90 % are confined to the more gentle slopes and shallow depressions, but they do ascend nearly to the top of the hill. Characteristic species are *Stipa concinna, Carex haematostoma, Viola kunawurensis* and *Gentianella azurea. Carex montis-everestii, Kobresia pusilla* and *Potentilla pamirica* inhabit the edges of the turf-spots towards the free gelifluction slopes. Cushions of *Thylacospermum* can be found between rocky outcrops and on relatively stable slopes. At 4900 m, the largest, somewhat disintegrated cushion of *Thylacospermum* had a diameter of 2.4 m. This should correspond to a high age (of several hundred years?).

Fig 14 The largest cushion of *Thylacospermum caespitosum* at 5060 m on a SW-facing wall of rock of a lateral gully E of and c. 100 m above of the upper K2-N-Glacier (c. 9 km NNW of K2 summit). Ice-axe 80 cm. (Photo: Sept. 11, 1986, B. Dickoré)

Higher up along the K2-N-Glacier, there are extensive scree slopes, which are devoid of vegetation, except for a small place of a few m^2 around 4950 m *(Sibbaldia, Saussurea, Elymus schrenkianus)*. The highest location where we could reach any vegetation was a steep rocky gully E of K2-N-Glacier (5060 m, 9 km NNW of K2-summit). The S-facing rock-wall of this had 4 species of higher plants *(Thylacospermum, Nepeta longibracteata, Silene gonosperma* and *Waldheimia tomentosa)*, whereas the N-facing rocks had a fairly rich cover of lichens. The *Thylacospermum*-cushions were of a considerable size here, but sterile (Fig 14). From a distance (Camp 2 on the medial moraine close to the north-wall of K2), we could observe *Thylacospermum*-cushions at least up to the altitude of 5200 m (7 km NNW of K2-summit).

Flora of the Transect

The annotated list (Tab 3) includes all species of Charophyta, Pteridophyta, and Spermatophyta collected by the German expedition party during the 1986 expedition between Kashgar (Tarim basin) and K2 (Karakoram). Regarding local and altitudinal distribution, additional field observations have been included, so far as misidentification is likely to be excluded. Some important synonyms are given, including a few supposed, but not checked synonyms ("?"). An informal aggregate conception ("s.l.") for uncertainty of species delimitation, or the formula "auct. non ..." for frequent misidentification is used especially in "arctic-alpine" species complexes.

Tab 3 Annotated list of plants collected in the Northern Declivity of the Karakoram/Kunlun Mountains (Charophyta, Pteridophyta, Spermatophyta)

Table key

1st column:
names of taxa (synonyms)

2nd column (facultative):
abbreviation of specialist's determination or confirmation of part or all of the material concerned:

1.	W. Krause	= WK	8.	P. Cribb	= PC
2.	H. Freitag & G. Maier-Stolte	= FM	9.	G. Wagenitz	= GW
3.	A. O. Chater	= AC	10.	C. Jeffrey	= CJ
4.	K. Lewejohann	= KL	11.	R. Doll	= RD
5.	T. A. Cope	= TC	12.	D. Podlech	= DP
6.	H. Freitag	= HF	13.	M. Lidén	= ML
7.	W. T. Stearn	= WS	14.	C. Grey-Wilson	= CG
			15.	J. Soják	= JS.

3rd column:
altitudinal distribution of the taxon indicated by the lowest and the highest record along the transect.

4th column:
Occurence ("x"), resp. no evidence (".") of the taxon in the subdivisions of the transect: left to right (= north-south):

1)	Kashgarian Lowland	(Ksg)	5)	Aghil Shan	(Agh)
2)	Kunlun Foothills	(Ksm)	6)	Shaksgam Valley	(Sha)
3)	Kunlun Shan (main ridge)	(Kun)	7)	Central Karakoram N slope	(Kar).
4)	Yarkand Valley	(Yar)			

1 Charophyta			
Characeae			
Chara contraria A.BRAUN ex KÜTZ. (Ch. vulgaris s.l.)	WK	3770 m	...x...
2 Pteridophyta			
2.1 Sphenopsida			
Equisetaceae			
Equisetum ramosissimum DESF.		3520 m	...x...
2.2 Pteropsida			
Athyriaceae			
Cystopteris dickieana R.SIM		4420-4550 m	x
3 Spermatophyta			
3.1 Gymnospermae			
Cupressaceae			
Juniperus pseudosabina FISCHER & MEYER		3200-3400 m	.x.....
Juniperus turkestanica KOMAROV		3980 m	x
3.2 Gnetatae			
Ephedraceae			
Ephedra fedtschenkoae PAULSEN	FM	3850-4420 m	....x.x
Ephedra intermedia SCHRENK & MEYER in C.A.MEYER var. intermedia	FM	3520-4160 m	..xxxxx
Ephedra intermedia var. glauca (REGEL) STAPF	FM	3550-4050 m	..xxx..
Ephedra monosperma J.G.GMELIN ex C.A.MEYER	FM	4380-4510 m	x
Ephedra regeliana FLORIN	FM	3100-4520 m	..x.x.x
3.3 Angiospermae			
3.3.1 Monocotyledonae			
Cyperaceae			
Blysmus sinocompressus TANG & WANG		3520-4060 m	...x.xx
Carex atrofusca SCHKUHR ssp. minor (BOOTT) T.KOYAMA	AC	3740-4780 m	..x.x..
Carex haematostoma NEES in WIGHT var. submacrogyna KÜKENTHAL		4750-4920 m	x
Carex melanantha C.A.MEYER in LEDEB.	AC	3760-3850 m	...x...
Carex microglochin WAHLENB.	KL	3760-3950 m	...x..x
Carex montis-everestii KÜKENTHAL (C. borii NELMES)	AC	4420-5030 m	....x.x
Carex nivalis BOOTT (C. griffithii BOOTT)		4380-4750 m	....x.x
Carex orbicularis BOOTT	AC	3760-4060 m	...x.xx
Carex pseudofoetida KÜKENTHAL (C. incurva auct. non LIGHTF.)		3930-4820 m	....x.x
Carex cf. pycnostachya KAR. & KIR.		4060 m	.....x.
Carex stenocarpa TURCZ. ex V.KRECZ. (? C. macrogyna auct. non TURCZ.)		4440-4760 m	....x.x
Carex stenophylla WAHLENB. (incl. C. stenophylloides V.KRECZ.)		4090 m	x
Eleocharis quinqueflora (F.X.HARTMANN) O.SCHWARZ ssp. meridionalis (ZINSERL.) EGOROVA		3050-4060 m	..xxxxx
Kobresia capillifolia (DECNE.) C.B.CLARKE		4560-4820 m	....x..
Kobresia deasyi C.B.CLARKE (K. tibetica auct. non MAXIM.)		3600-4780 m	...xx..
Kobresia pusilla IVANOVA		4380-5030 m	x
Kobresia royleana (NEES) BOECK.		3000-4780 m	..xxx..
Kobresia stenocarpa (KAR. & KIR.) STEUDEL		3930-4060 m	xx
Gramineae (Poaceae)			
Bromus japonicus THUNB.	TC	3000 m	..x....
Calamagrostis cf. epigeios (L.) ROTH		4100 m	x
Calamagrostis holciformis JAUB. & SPACH (Deyeuxia compacta MUNRO ex HOOKER f.)	TC	3900-4900 m	...xxxx
Calamagrostis pseudophragmites (HALLER f.) KOELER	TC	3000-3980 m	..xxxxx
Cynodon dactylon (L.) PERS.		1300 m	x......
Echinochloa crus-galli (L.) P.BEAUV.		1300,1400 m	x......
Elymus cf. dentatus (HOOKER f.) COPE	TC	3720-3850 m	....x..
Elymus nutans GRISEB. (E. sibiricus auct. non L.)	TC	3000-4200 m	..xxxxx
Elymus schrenkianus (FISCHER & MEYER) TZVELEV	TC	3850-5030 m	..x.x.x
Eremopoa altaica (TRIN.) ROSHEV. in KOM. ssp. songorica (SCHRENK) TZVELEV	TC	3600 m	...x...
Festuca olgae (REGEL) KRIVOT. (Leucopoa albida auct. non V.KRECZ. & BOBROV)	TC	3990-4630 m	..x.x.x
Festuca tibetica (STAPF) ALEXEEV (F. valesiaca auct. non GAUDIN)	TC	4340-5020 m	..x.x.x
Hordeum brevisubulatum (TRIN.) LINK ssp. turkestanicum (NEVSKI) TZVELEV	TC	3600-4060 m	..xx.xx
Koeleria litwinowii DOMIN		4380 m	..x....
Leymus secalinus (GEORGI) TZVELEV	TC	3000-4560 m	.xxxxxx
Phragmites australis (CAV.) TRIN. ex STEUDEL		1600-3900 m	x.xx...
Phragmites cf. humilis DE NOT.		1280 m	x......
Poa calliopsis LITW. ex OVCZ.		4000-4660 m	..x.x..
Poa litvinoviana OVCZ.		4370-4420 m	..x...x
Poa poophagorum BOR	TC	3050-5020 m	..x.x.x
Polypogon monspeliensis (L.) DESF.	TC	3000 m	..x....
Puccinellia distans (WAHLENB.) PARL.	TC	1280-3050 m	x.x....
Puccinellia kashmiriana BOR	TC	3930,3980 m	xx
Puccinellia tenuiflora (TURCZ.) SCRIBNER & MERR.		3520-4820 m	..xxxxx
Setaria glauca (L.) P.BEAUV.		1400 m	x......
Stipa caucasica SCHMALH. ssp. glareosa (SMIRNOV) TZVELEV	HF	3600-4520 m	..xxxxx
Stipa concinna HOOKER f.	HF	4560-5000 m	....x.x
Stipa orientalis TRIN. in LEDEB.	HF	3630 m	...x...
Stipa purpurea GRISEB.	HF	3990-4640 m	..x.x.x
Stipa splendens TRIN. in SPRENGEL	HF	1600-4130 m	xxxxx.x
Stipa subsessiliflora (RUPR.) ROSHEV.	HF	4130-4660 m	..x.x.x
Juncaceae			
Juncus ambiguus GUSS. (J. ranarius SONG. & PERR. in BILLOT)		3000 m	..x....
Juncus articulatus L.		1280 m	x......
Juncus membranaceus ROYLE ex DON		3700 m	....x..
Juncus thomsonii BUCHENAU		4620 m	....x..
Juncus triglumis L.		3740,4210 m	..x....
Juncaginaceae			
Triglochin maritima L.		3850-4060 m	...x.x.
Triglochin palustris L. (T. himalensis ROYLE)		3000-4060 m	..xxxxx
Liliaceae			
Allium carolinianum DC. in REDOUTÉ	WS	4360-4520 m	....x.x
Allium filifolium REGEL	WS	3050-4000 m	.xx.x..
Allium cf. humile KUNTH	WS	3970 m	x
Allium sp.		2280 m	.x.....
Asparagus cf. angulofractus ILJIN		2540 m	.x.....
Lloydia serotina (L.) REICHENB.		4550 m	x
Orchidaceae			
Dactylorhiza kafiriana RENZ in RECH.f. (D. umbrosa auct. non NEVSKI)	PC	3760-3850 m	...x...
Potamogetonaceae			
Potamogeton pectinatus L. (incl. P. filiformis var. tibetanus HAGSTR.)	KL	3770 m	...x...

3.3.2 Dicotyledonae

Amaranthaceae
Amaranthus graecizans L. 1300 m x......

Apocynaceae
Apocynum hendersonii HOOKER f. in HENDERSON & HUME (Poacynum hendersonii (HOOKER f.) WOODSON) 1600 m x......

Asclepiadaceae
Cynanchum acutum L. 1300,1600 m x......

Berberidaceae
Berberis ulicina HOOKER f. & THOMSON (B. kaschgarica RUPR.) 3000-4300 m ..xxxxx

Boraginaceae
Arnebia guttata BUNGE (A. tibetana KURZ, Lithospermum guttatum (BUNGE) I.M.JOHNSTON) 3600-4300 m ...xxxx
Eritrichium rupestre s.l. 3050-4400 m ..xxx.x
(incl.:) E. cf. rupestre BUNGE 3050-4400 m ..xxx.x
E. sp. 4200 m ....x..
Eritrichium spathulatum (BENTHAM in ROYLE) C.B.CLARKE 4610 m x
Hackelia cf. pamirica (B.FEDTSCH.) BRAND 3700 m ....x..
Microula tibetica BENTHAM in BENTHAM & HOOKER f. 4160,4570 m ..x.x..

Caprifoliaceae
Lonicera asperifolia (DECNE.) HOOKER f. & THOMSON 3850-4440 m ....x.x
Lonicera semenovii REGEL (L. glauca HOOKER f. & THOMSON, non HILL) 4100-4910 m x

Caryophyllaceae
Lepyrodiclis holosteoides (C.A.MEYER) FENZL ex FISCHER & MEYER 3000 m ..x....
Silene gonosperma (RUPR.) BOCQUET ssp. himalayensis (ROHRB.) BOCQUET (Melandrium apetalum auct. non (L.) FENZL) 4380-5050 m ..x.x.x
Silene moorcroftiana WALL. ex BENTHAM in ROYLE 3880-4460 m ....x.x
Stellaria cf. decumbens HOOKER f. & THOMSON 4750-4770 m x
Stellaria irrigua BUNGE (St. umbellata TURCZ., St. subumbellata EDGEW.) 3740 m ..x....
Thylacospermum caespitosum (CAMBESS.) SCHISCHK. (Arenaria caespitosa (CAMBESS.) KOZHEVN.) 4100-5200 m x

Chenopodiaceae
Atriplex sibirica L. (incl. A. centralasiatica ILJIN) 2280-3600 m .xxx...
Axyris prostrata L. 4160 m ....x..
Axyris cf. sphaerosperma FISCHER & MEYER 4570 m ..x....
Bassia dasyphylla (FISCHER & MEYER) O.KUNTZE (Echinopsilon divaricatum KAR. & KIR.) 2100,3930 m x.....x
Chenopodium acuminatum WILLD. 1300 m x......
Chenopodium album L. 1300 m x......
Chenopodium glaucum L. 1300-3800 m x..x...
Chenopodium cf. prostratum BUNGE 3520-4570 m ..xxx..
Chenopodium schraderianum SCHULTES in ROEMER & SCHULTES (Ch. foetidum SCHRADER, non LAM.) 3600 m ...x...
Corispermum tibeticum ILJIN 3740 m ...x...
Halogeton arachnoideus MOQ. in DC. 2280-3930 m .x.x..x
Halogeton glomeratus (M.BIEB.) C.A.MEYER in LEDEB. 1400-3100 m xxx....
Haloxylon ammodendron (C.A.MEYER) BUNGE 1350 m x......
Haloxylon cf. persicum BUNGE ex BOISS. & BUHSE 1350 m x......
Kalidium cuspidatum (UNG.-STERNB.) GRUBOV 3020,3300 m .xx....
Kochia melanoptera BUNGE 3100 m ..x....
Kochia scoparia (L.) SCHRADER 1300 m x......
Krascheninnikovia ceratoides (L.) GUELDENST. s.l. (Eurotia ceratoides (L.) C.A.MEYER, Ceratoides latens (J.F.GMELIN) REVEAL & HOLMGREN, C. papposa (PERS.) BOTSCH. & IKONN.) 3100-4400 m .xxxxxx
Krascheninnikovia compacta (LOSINSK.) GRUBOV (Eurotia compacta LOSINSK., Ceratoides compacta (LOSINSK.) TSIEN & C.G.MA) 4570-4720 m ..x.x..
Salsola collina PALLAS 1600-3600 m x..x...
Salsola cf. pestifer NELSON in COULTER 1400,1900 m x......
Salsola sp. (aff. S. chinghaiensis A.J.LI) 3930 m x
Spinacia oleracea L. 1300 m x......
Suaeda corniculata (C.A.MEYER) BUNGE 3000,3870 m ..xx...
Sympegma regelii BUNGE 2150-3870 m .xxx...

Compositae(Asteraceae)
Acroptilon repens (L.) DC. GW 1300 m x......
Ajania fruticulosa (LEDEB.) POLJAK. (Tanacetum fruticulosum LEDEB., incl. T. gracilis HOOKER f. & THOMSON) CJ 2540-4370 m .xxxxxx
Ajania tibetica (HOOKER f. & THOMSON) TZVELEV (Tanacetum tibeticum HOOKER f. & THOMSON) CJ 3880-4980 m ..x.x.x
Artemisia compacta FISCHER ex DC. (A. maritima s.l.) CJ 3270-4150 m .x..x..
Artemisia macrocephala JACQUEM. ex BESSER CJ 3000-3930 m .xxxx.x
Artemisia pamirica WINKLER (A. dracunculus s.l.) 3550-4570 m ..xxx.x
Artemisia santolinifolia TURCZ. ex KRASCH. in KRYLOV CJ 3620-4370 m ...xx.x
Artemisia cf. scoparia WALDST. & KIT. 3000 m ..x....
Artemisia stricta EDGEW. (incl. A. demissa KRASCH.) CJ 3700-4350 m ....x..
Artemisia tournefortiana REICHENB. (A. biennis auct. non L.) GW 1300 m x......
Artemisia wellbyi HEMSLEY & PEARSON (A. salsoloides auct. non WILLD.) CJ 3680-3980 m xxx
Aster flaccidus BUNGE ssp. flaccidus 4380 m ..x....
Aster tripolium L. GW 1280 m x......
Brachyactis ciliata (LEDEB.) LEDEB. CJ 1280 m x......
Brachyactis roylei (DC.) WENDELBO 3000 m ..x....
Cirsium arvense (L.) SCOP. 3520-4060 m ..xxxx.
Crepis flexuosa (DC.) C.B.CLARKE 3000-4500 m ..xxxxx
Dolomiaea macrocephala ROYLE (Jurinea dolomiaea BOISS.) CJ 3920-4550 m ....x.x
Inula salsoloides (TURCZ.) OSTENF. in HEDIN 1400 m x......
Lactuca tatarica C.A.MEYER 1300-3940 m x.xxx.x
Launaea sp. (Chondrilla polydichotoma OSTENF. in HEDIN) CJ 1280-2150 m x......
Leontopodium cf. brachyactis GANDOGER CJ 3050 m ..x....
Leontopodium nanum (HOOKER f. & THOMSON) HANDEL-MAZZ. CJ 3100-5000 m ..x.x.x
Saussurea gnaphalodes (ROYLE) SCHULTZ BIP. 4380-5030 m ..x.x.x
Scorzonera songorica (KAR. & KIR.) LIPSCH. & VASSILCZ. 1280 m x......
Senecio krascheninnikovii SCHISCHKIN CJ 3000,3800 m ..xx...
Tanacetum pyrethroides (KAR. & KIR.) SCHULTZ BIP. CJ 3850-4610 m ....x.x
Taraxacum asiaticum DAHLST. RD 3930 m x
Taraxacum himalaicum V.SOEST RD 4260 m ....x..
Taraxacum kashmirense V.SOEST RD 4380,4780 m ..x.x..
Taraxacum ludlowii V.SOEST RD 3020,3600 m ..xx...
Taraxacum luridum HAGLUND RD 2980 m ..x....
Taraxacum stenolepium HANDEL-MAZZ. RD 4620 m ....x..
Taraxacum wendelboanum V.SOEST RD 3930 m x
Waldheimia tomentosa (DECNE.) REGEL 4200-5050 m ..x...x
Waldheimia tridactylites KAR. & KIR. ssp. tridactylites 4940 m x
Xanthium strumarium L. (incl. X. sibiricum PATR. ex WIDDER, X. japonicum WIDDER) GW 1300 m x......

Convolvulaceae
Convolvulus arvensis L. 1300,1400 m x......

Crassulaceae
Orostachys thyrsiflora (DC.) FISCHER ex SWEET 2280-4520 m .xx.x..
Rhodiola fastigiata (HOOKER f.) FU 4250-5020 m ....x.x
Rhodiola himalensis (D.DON) FU 4050-4380 m ..x....

Cruciferae(Brassicaceae)
Braya pamirica (KORSH.) O.FEDTSCH. 4380 m ..x....
Braya rosea (TURCZ.) BUNGE 3000-3740 m ..x....
Braya thomsonii HOOKER f. 4380 m ..x....
Braya tibetica HOOKER f. & THOMSON 3700-4620 m ..x.x..
Cardaria pubescens (C.A.MEYER) ROLLINS 3520 m ...x...
Christolea crassifolia CAMBESS. in JACQUEM. 3560-4450 m ..xxxxx
Christolea cf. linearis N.BUSCH 4220 m x
Dilophia salsa THOMSON in HOOKER f. 3620-4620 m ..xxxxx
Draba altaica (C.A.MEYER) BUNGE 4150-4820 m ....x.x
Draba glomerata ROYLE 4610 m x
Draba oreades SCHRENK in FISCHER & MEYER 4780,4950 m ..x.x..
Draba winterbottomii (HOOKER f. & THOMSON) POHLE 4790 m x
Hedinia tibetica (THOMSON) OSTENF. in HEDIN 4570 m ..x....
Hymenolobus pauciflorus (KOCH) SCHINZ & THELL. (? Draba tenerrima O.E.SCHULZ) 3940 m x
Lepidium apetalum WILLD. 3000-4160 m .xxxx..
Lepidium latifolium L. 3000-3870 m ..xxx..
Malcolmia africana (L.) R.BR. 3270 m .x.....
Malcolmia cf. behboudiana RECH.f. & ESF. 3600 m ...x...
Malcolmia intermedia C.A.MEYER 3000 m ..x....
Parrya exscapa LEDEB. 3940-4760 m ..x.x.x
Ptilotrichum canescens (DC.) C.A.MEYER in LEDEB. 4170-4520 m ....x.x
Torularia cf. brevipes O.E.SCHULZ 3800 m ...x...
Torularia humilis (C.A.MEYER) O.E.SCHULZ 3880-4620 m ..x.x..

Elaeagnaceae
Elaeagnus angustifolia L. 2100 m x......
Hippophae rhamnoides L. ssp. turkestanica ROUSI 3500-3740 m ...x...

Gentianaceae
Gentiana aquatica s.l. 3000-4100 m ..x..xx
(incl.:) G. leucomelaena MAXIM. 3000,4100 m ..x....
G. cf. pseudoaquatica KUSNEZ. 3930,4060 m xx
Gentiana karelinii GRISEB. in DC. (G. prostrata s.l.) 4260-4560 m ..x.x..
Gentianella azurea (BUNGE) H.SMITH 4260-5030 m ....x.x
Gentianella falcata (TURCZ. ex KAR. & KIR.) H.SMITH 4780-4820 m ....x..
Gentianella pulmonaria (TURCZ. ex LEDEB.) V.ZUEV 3000 m ..x....
Gentianella pygmaea (REGEL & SCHMALH.) H.SMITH (Gentiana thomsonii C.B.CLARKE in HOOKER f.) 3740-5000 m ..xxx.x

Gentianella cf. stoliczkae (C.B.CLARKE) TOYOKUNI (G. aurea s.l.) 3000 m ..x....
Gentianella vvedenskyi (GROSSH.) H.SMITH (G. detonsa s.l.) 3000-3850 m ..xx...
Lomatogonium brachyantherum (C.B.CLARKE) FERNALD 4370-4420 m x
Lomatogonium thomsonii (C.B.CLARKE) FERNALD (L. carinthiacum auct. non (WULFEN) REICHENB.) 3000-4560 m ..xxxxx

Geraniaceae
Geranium collinum STEPH. ex WILLD. 3000 m ..x....

Grossulariaceae
Ribes cf. villosum WALL. in ROXB. (R. orientale s.l.) 3970 m x

Labiatae(Lamiaceae)
Dracocephalum heterophyllum BENTHAM 3920-4620 m ..x.x.x
Dracocephalum stamineum KAR. & KIR. 3570-4550 m ..xxx.x
Nepeta longibracteata BENTHAM 4400-5050 m ....x.x

Leguminosae(Fabaceae)
Alhagi kirghisorum SCHRENK 1400-2100 m x......
Astragalus densiflorus KAR. & KIR. DP 4380 m ..x....
Astragalus melanocarpus BUNGE DP 3740 m ..x....
Astragalus nivalis KAR. & KIR. DP 4350-4700 m ..x.x.x
Astragalus strictus GRAHAM ex BENTHAM DP 3000-4620 m ..x.x.x
Astragalus tibetanus BENTHAM ex BUNGE DP 3050-3930 m .xxx..x
(incl.:) A. cf. chadjanensis FRANCHET 3050,3270 m .xx....
A. tibetanus s.str. 3620-3930 m ...x..x
Astragalus webbianus GRAHAM ex BENTHAM in ROYLE DP 4320-4500 m x
Caragana polourensis FRANCHET 2540-3300 m .x.....
Cicer songoricum STEPH. ex DC. 3650-4380 m ....x.x
Oxytropis ampullata (PALLAS) PERS. 3650-4780 m ....x..
Oxytropis cf. chiliophylla ROYLE ex BENTHAM (O. microphylla auct. non (PALLAS) DC., O. hedinii ULBRICH, ? O. de-filippii PAMP.) 3700-4800 m ...xx.x
Oxytropis chionobia BUNGE 4780-4820 m ....x..
Oxytropis densa BENTHAM ex BUNGE 4150-4560 m ....x..
Oxytropis glabra s.l. 3000-4060 m ..xx.xx
(incl.:) O. glabra (LAM.) DC. 3000-3850 m ..xx...
O. hirsutiuscula FREYN 3000-4060 m ..x..xx
O. hypoglottoides (BAKER) ALI 3850 m ...x...
Oxytropis humifusa KAR. & KIR. 4380 m ..x....
Oxytropis immersa (BAKER ex AITCH.) BUNGE ex FEDTSCH. 4380,4570 m ..x...x
Oxytropis microphylla (PALLAS) DC. 3550-4440 m ..xxxxx
Oxytropis pagobia BUNGE 4150-4820 m ....x..
Oxytropis sp. 4750-5030 m x
Thermopsis alpina (PALLAS) LEDEB. 3740 m ..x....
Thermopsis inflata CAMBESS. in JACQUEM. 4570 m ..x....

Orobanchaceae
Cistanche salsa (C.A.MEYER) G.BECK in ENGLER & PRANTL 2280-3020 m .xx....
Orobanche cernua LOEFL. 1600 m x......

Papaveraceae
Corydalis adiantifolia HOOKER f. & THOMSON s.l. (? C. n.sp.) ML 3570-4400 m ..xxxxx
Corydalis crassissima JACQUEM. ex CAMBESS. in JACQUEM. (C. crassifolia auct. non ROYLE) ML 4310-4740 m x

Parnassiaceae
Parnassia laxmanni PALLAS ex SCHULTES 3000 m ..x....

Plantaginaceae
Plantago gentianoides SIBTH. & SM. ssp. griffithii (DECNE.) RECH.f. 3740 m ..x....
Plantago minuta PALLAS 2540,2650 m .x.....

Plumbaginaceae
Acantholimon diapensioides BOISS. in DC. 3270-3300 m .x.....

Polygonaceae
Calligonum mongolicum TURCZ. s.l. (? incl. C. roborowskii LOSINSK., ? C. yengisaricum Z.M.MAO) 1350,1600 m x......
Oxyria digyna (L.) HILL 3050 m ..x....
Polygonum gracilius (LEDEB.) KLOKOV (P. bellardii s.l.) 3000 m ..x....
Polygonum cf. oxyspermum C.A.MEYER & BUNGE ex LEDEB. 1400 m x......
Polygonum pamiricum KORSH. (P. sibiricum LAXM. ssp. thomsonii (MEISNER) RECH.f. & SCHIMAN-CZEIKA) 3770 m ...x...
Polygonum viviparum L. 3740-4620 m ..x.x..
Rheum spiciforme ROYLE 4150-4790 m ..x.x.x
Rheum tibeticum MAXIM. ex HOOKER f. (? Rh. fedtschenkoi MAXIM. ex REGEL) 3790-4040 m ....x.x
Rheum sp. (aff. Rh. racemiferum MAXIM.) 3870-3950 m .....x.
Rumex angulatus RECH.f. (R. longifolius s.l.) 3000 m ..x....

Primulaceae
Androsace flavescens MAXIM. 3050-5000 m ..x.x.x
Androsace squarrosula MAXIM. 3000-4100 m .xx....
Glaux maritima L. 3520-3930 m ..xx..x
Primula macrophylla D.DON (P. nivalis s.l.) 4620-4780 m ....x..
Primula pamirica FEDOROV (P. sibirica s.l.) 3000-4060 m ..xx.xx

Ranunculaceae
Clematis tangutica (MAXIM.) KORSH. (C. orientalis s.l.) 3000-3870 m ..xxx..
Delphinium brunonianum ROYLE CG 4380-5000 m ....x.x
Ranunculus pulchellus C.A.MEYER s.l. 3740-4820 m ..x.x..
(incl.:) R. cf. krasnovii OVCZ. 4780-4820 m ....x..
R. longicaulis C.A.MEYER 3740 m ..x....
R. cf. pamiri KORSH. 4260,4460 m ....x..
R. cf. pseudohirculus SCHRENK 4620 m ....x..
Ranunculus sarmentosus ADAMS (R. salsuginosus auct. non GREEN) 3000 m ..x....

Rhamnaceae
Rhamnus prostrata JACQ. ex PARKER 3820-4160 m ....x.x

Rosaceae
Chamaerhodos sabulosa BUNGE in LEDEB. JS 3650-4520 m xxx
Dasiphora dryadanthoides JUZ. (Potentilla fruticosa var. pumila HOOKER f. p.p.) JS 3850-5020 m ..x.x.x
Potentilla agrimonioides M.BIEB. JS 3990-4520 m ....x..
Potentilla bifurca L. ssp. orientalis (JUZ.) SOJAK (P. moorcroftii WALL.) JS 3000-4750 m ..xxx.x
Potentilla gelida C.A.MEYER ssp. borissii (OVCZ. & KOCZK.) SOJAK JS 4750 m x
Potentilla multifida L. JS 3000-4720 m .xxxx.x
Potentilla pamirica WOLF X P. sino-nivea HULTÉN JS 4150-5030 m ..x.x.x
(incl.:) P. cf. pamirica WOLF 4590-5030 m ....x.x
P. cf. pamiroalaica JUZ. 4780-4820 m ....x..
P. cf. saundersiana ROYLE 4150-4620 m ....x..
P. cf. thomsonii HANDEL-MAZZ. 4380 m ..x....
Potentilla salesoviana STEPH. (Comarum salesovianum (STEPH.) ASCHERSON & GRAEBNER) JS 3620-4380 m ..xxxxx
Potentilla virgata LEHM. (P. dealbata BUNGE in LEDEB.) JS 3930,4060 m xx
Sibbaldia olgae JUZ. & OVCZ. JS 4760 m x
Sibbaldia tetrandra BUNGE JS 4560-5030 m ..x.x.x
Sibbaldianthe adpressa (BUNGE) JUZ. JS 4520 m ....x..

Rubiaceae
Rubia tibetica HOOKER f. 3870-4300 m ...x.xx

Salicaceae
Populus diversifolia SCHRENK (incl. P. litwinowiana DODE) 1600 m x......
Salix pycnostachya ANDERS. 3920-3950 m x
Salix cf. sericocarpa ANDERS. 3000,3800 m ..xx...

Saxifragaceae
Saxifraga cernua L. 4780 m ....x..
Saxifraga hirculus L. var. alpina ENGLER 4620-4820 m ....x..
Saxifraga oppositifolia L. ssp. asiatica (HAYEK) ENGLER & IRM. 4780 m x
Saxifraga pulvinaria H.SMITH (S. imbricata ROYLE, non LAM.) 4070-4810 m ....x.x

Scrophulariaceae
Euphrasia cf. schlagintweitii WETTST. 3050-3950 m ..xx..x
Lagotis decumbens RUPR. 4380-4960 m ..x.x.x
Lagotis globosa (KURZ) HOOKER f. 4760-4810 m x
Pedicularis cheilanthifolia SCHRENK 3000-4820 m ..x.x.x
Scrophularia scoparia PENNELL 3570-4390 m ..xxx.x

Solanaceae
Lycium ruthenicum MURRAY 2100-2150 m .x.....
Solanum luteum MILLER 1300 m x......
Solanum nigrum L. 1300,1400 m x......

Tamaricaceae
Myricaria bracteata ROYLE (M. alopecuroides SCHRENK, M. germanica s.l.) 3200-4360 m ..xxxxx
Myricaria elegans ROYLE 3550-4130 m ...xx.x
Myricaria pulcherrima BATALIN 1400 m x......
Reaumuria soongorica (PALLAS) MAXIM. (Hololachne soongorica PALLAS, H. shawiana HOOKER f. in HENDERSON & HUME) 2540-3300 m .x.....
Tamarix chinensis LOUR. 3550 m ....x..
Tamarix ramosissima LEDEB. 1280 m x......

Umbelliferae(Apiaceae)
Carum cf. carvi L. 3000 m ..x....
Eriocycla thomsonii (C.B.CLARKE) WOLFF in ENGLER 3050 m ..x....
Heracleum pinnatum C.B.CLARKE in HOOKER f. 3600-4380 m ...xxxx
Pachypleurum mucronatum (SCHRENK) SCHISCHKIN in KOM. (Neogaya mucronata SCHRENK) 3740 m ..x....
Pleurospermum govanianum (DC.) C.B.CLARKE (Hymenolaena govaniana DC.) 4350-4610 m x
Pleurospermum lindleyanum (KLOTZSCH) DIELS (P. stellatum auct. non (D.DON) BENTHAM) 4380-4960 m ..x.x..

Violaceae
Viola biflora L. 4150-4610 m ....x.x
Viola kunawurensis ROYLE 4460-5000 m x
Viola cf. tianschanica MAXIM. 3740 m ..x....

Zygophyllaceae	
Nitraria schoberi L.	2050-3740 m xxxx...
Peganum harmala L.	2050-3710 m xxxx...
Zygophyllum lehmannianum BUNGE	1600,3520 m x..x...
Zygophyllum xanthoxylon (BUNGE) MAXIM.	1350,1600 m x......
Pachypleurum mucronatum (SCHRENK) SCHISCHKIN in KOM. (Neogaya mucronata	

There is no modern taxonomic list to be taken as a basis for determination of our material. We used as standard floras, although often incomplete and diverging in many respects: Flora Reipublicae Popularis Snicae (eds., 1978–); Grubov et al. (1966–1977); Hara, Williams et al. (1978–1982); Hooker (1875–1897); Komarov et al. (1934–1964); Nasir, Ali et al. (1970–); Ovčinnikov et al. (1957–); Rechinger et al. (1963–); Tutin et al. (1964–1980). Monographical studies were included as far as available; these are not cited separately. Herbarium material was compared from the herbaria of Göttingen (GOET) and Berlin-Dahlem (B). However, the most successful work on the examination of critical material could be done in London, where I stayed for two weeks at Kew (K), and visited also the British Museum, Natural History (BM).

Apart from the material that has been kindly determined by specialists, there remained a lot of uncertainty. For this, the author might be excused by the often insufficient material, which had been collected rather late in the year and with many species rare or even found in single specimens. Additionally, much of the flora of the KKND belongs to some of the largest and most difficult holarctic genera, that often display very complex radiation and differentiation patterns around the Tibetan Plateau.

Chorology

We desist from giving calculations on geoelements present in the flora of the KKND, since there are numerous ambiguities caused by lack of data, confusion or contradictionary application of phytogeographical terms, or delimitation and assignement of each species. Zheng Du (1983) provided a valuable phytogeographical analysis of the Tibetan plateau. Most recently, Huang Rongfu (1988) presented a chorological subdivision on generic level of the flora of the W Mt. Everest area. According to Zheng Du (1983), the flora of the NW projection of the Tibetan plateau entirely consists of Centralasiatic, Tibetan and Northern geoelements.

The flora of the KKND generally is characterized by the dominance of wide-spread Holarctic taxa with only very few (neo-) endemics. With reference to the classification outlined by Clayton&Cope (1980), and other frequently used systems, most of the flora of the KKND would fall into the following categories:

Cosmopolitic, Pantemperate/Holarctic, Circumpolar, Eurasiatic, Central Asiatic and Saharo-Mongolian ("Tethys elements", cf. Huang Rongfu 1988), Tibetan (see below).

Interesting is the almost perfect exclusion of Irano-Turanian and Sino-Himalayan elements from the flora of the KKND. This is only slightly modified in the outer mountain ranges. Tropical elements are completely lacking. Characteristic large Irano-Turanian genera are represented in our area only by single *(Acantholimon, Nepeta)* or comparatively few species *(Astragalus)*, while others lack completely *(Cousinia, Dionysia)*. Sino-Himalayan elements, according to numerous examples provided by Meusel&Schubert (1971), are completely absent from the KKND. However, much of the holarctic "arctic-alpine" genera exhibit maximum species diversities in the Sino-Himalayan/SE Tibetan area. Of such genera, only *Kobresia, Braya* and *Gentianella* (Sect. *Comastoma*) are somewhat better represented in the KKND, while there occur only single species of other large genera of similar distribution types *(Corydalis, Saxifraga, Primula, Gentiana, Leontopodium, Saussurea)*.

The different floristic character and higher species diversities of high mountain regions closely adjoining to the west, south and south-east, generally corresponds to a better representation of Irano-Turanian and Sino-Himalayan elements there. Numerous examples can be found, when the flora of the KKND is compared to floras or vegetation descriptions and related works, for example, from the Pamirs (Ovčinnikov et al. 1957–), Wakhan (Kitamura 1964; Grey-Wilson 1974; Podlech&Anders 1977), Hindu Kush (Breckle 1974), the Karakoram S Slope (Pampanini 1930; Gilli 1957; Kitamura 1960; Hartmann 1966, 1968, 1972), Chitral (Wendelbo 1952), Zanskar (Seybold&Kull 1985) and Ladakh (Hartmann 1984).

"Tibetan elements" certainly do not represent a homogenous group. None of the genera endemic to SE Tibet (cf. Ni Zhi-Cheng&Cheng Shu-Zhi 1987) occur in the Karakoram/Kunlun N declivity. On the other hand, some of the few local genera endemic to High Asia *(Dilophia, Thylacospermum, Microula, Waldheimia)*, which have been mentioned by Hemsley (1902), do occur. Species common to the dry NW Tibetan plateau or distributed over large parts of High Asia seem to comprise the largest group of the flora of the KKND.

Conclusions

Assumed that the flora and vegetation of the KKND, as documented above, reflect actual climatic conditions as well as the environmental history, some conclusions may be made.

Human influence generally is low in the KKND, but locally evident to the N of the Aghil Shan ridge, less so, but already detectable, in the Shaksgam valley and in the central Karakoram N slope. Floristically, the distribution of loess, which extends S to the alpine belt of the Kunlun Shan N slope, probably is most distinctive. The Kunlun Shan main ridge has also been considered an important borderline on thermoclimatical (Zhang et al. 1981) and palaeobotanical (Hsü Jen 1984) grounds.

The vegetation history of the Tibetan plateau, as evident from fossil floras and summarized by Hsü Jen (1982, 1984), is that of a gradual impoverishment of a rich Tertiary flora towards present wide-spread steppe, semi-desert and desert conditions during the uplift of the area; followed by cyclic large-scale glaciation (Kuhle 1988) during the Pleistocene. This generally applies also to the Karakoram/Kunlun mountains, where moraines descend to c. 1900 m on the edge of the Tarim basin. However, the extreme relief energy and the marginal position of the KKND against the Tibetan plateau should have enabled the survival of nunatak floras, as well as a certain migration activity of plant species, corresponding to the fluctuation of glaciers and climatical conditions. The farreaching effects of the Tibetan plateau on the actual climatic and vegetational situation and division of E Asia have been summarized by Chang (1984).

As a product of former and recent conditions, the species-poor flora of the KKND is an essentially Holarctic-Centralasian-Tibetan one, of an extremely marginal position within the Holarctic/Pantemperate Kingdom, but almost completely excluding elements of closely neighbouring geobotanical division units (Tropical, Irano-Turanian, Sino-Himalayan). Thus, the KKND may be considered part of a "filter" in a migration path between the Sino-Himalayan and other northern hemisphere mountain floras, and, on the other hand, as a barrier between the palaeotropic Saharo-Sindian and the holarctic Centralasian-Mongolian desert floras.

According to the orographical structure, five horizontal vegetation zones can be extracted. These reflect features of widely distributed vegetation units, but are extremely narrowed in the KKND:

1) Kashgarian lowland

This is equivalent to the colline zone up to the foot of the mountains. Temperate stone-, more rarely alluvial loess- and sand-deserts, and oases comprise the westernmost extension of the Mongolian vegetation-province. The Kashgarian flora is exceedingly poor in species compared to the E Mongolian, as well as to the Middle Asiatic floras W of the bordering mountains. Beneath of wide-spread desert shrubs (*Haloxylon ammodendron, Calligonum mongolicum* s.l.), endemics are few (*Myricaria pulcherrima, Apocynum hendersonii*).

2) Kunlun foothills

The zone includes montane and subalpine loess-deserts and -steppes. It is part of a vegetation belt, which borders much of the central Asiatic high mountains and which interruptedly extends along the N rim of Tibet E to the large loess plateau area of Gansu. Common Centralasiatic species (*Sympegma regelii, Juniperus pseudosabina*) and a few Irano-Turanian elements (*Reaumuria soongorica, Acantholimon diapensioides*) occur in the W part.

3) Kunlun Shan N slope

Along the KKND, this is the richest in species, including Central- and N Asian elements, possibly also the (relatively) highest concentration of Sino-Himalayan elements (*Braya thomsonii, Rhodiola himalensis*). The border between the Mongolian and the Tibetan vegetation provinces (Grubov et al. 1977) can be drawn over the Kunlun N slope. There are some endemics (*Braya pamirica, Koeleria litwinowiana*) and additional species indicating a certain role of the Kunlun N slope as a glacial refuge and inter-glacial migration path (*Thermopsis alpina, Th. inflata*). Thus, the "Kunlun-Corridor" on the N margin of Tibet may be set against the Himalayan-Corridor (Tabata 1988) on the S rim of Tibet. However, since forests are absent and the comparatively poor flora includes only a few extant endemics, the "Kunlun-Corridor" is by far less important and conspicuous than the Himalayan.

4) Aghil Shan N slope/intramontane Yarkand valley

This can be considered a transitional zone between NW central Asian and Tibetan high mountain vegetation or part of a "Circumtibetan Zone". Similar vegetation features seem to be wide-spread around the extremely dry and high interior of Tibet. Accordingly, many of the species are widely distributed at least over NW Tibet and extend variously into adjacent mountain ranges such as the Tian Shan, the Pamirs, the Hindu Kush and more distant systems.

Typical species possibly are *Kobresia deasyi* and *Primula macrophylla*; for certain groups within large holarctic genera such as *Oxytropis, Potentilla, Gentianella* sect. *Comastoma* this zone may represent a centre of diversity.

5) Central Karakoram N slope/Shaksgam valley

This displays vegetation features of the most central high mountains and the interior valleys of the Pamir-Karakoram-Himalaya-S Tibet system. *Carex montis-*

everestii, Oxytropis cf. *chiliophylla, Potentilla pamirica* and *Thylacospermum caespitosum* may be considered characteristic for the innermost section of the Karakoram N slope. Obviously, there is a strong similarity within the flora of the highest mountain ranges on earth, along of a more than 2000 km long, but narrow and interrupted tract, which extends from the highest Pamir peaks at least to the Everest region. On the other hand, the poor flora of the central Tibetan high plateau (Changtang) does not seem to be positively represented in that of the Karakoram N slope; but the isolated ice-peaks of central Tibet may hold floras similar to that of the dry side of the extended Himalayas.

In contrary to the latitudinal zones, the altitudinal vegetation belts should reflect actual climatic conditions fairly accurate. However, in younger geological history both glaciation and extensive fluctuation of climate conditions versus elevation, must have had a certain effect of impoverishment on the flora. It is thus interesting, that the few species mentioned by Hartmann (1968) as pioneering the tongue basin only 20 m from the Biafo glacier of the Karakoram S slope, all are frequent in the Karakoram N declivity. On the other hand, most of those occuring only in greater distances from the Biafo glacier tongue, we did not find in the N declivity at all. As already emphasized above, the border between the subalpine and alpine vegetation belts (4380 m) is particulary well marked in the central Karakoram N slope. Since changes within species pairs occur, as well as isolated species confined to a narrow transition zone, we could tend to interpret this as an important climatical borderline, rather than a historical relic or edaphically determined. We suppose this being identical with the altitude of the mean annual 0 °C – isotherme, which under extremely dry situations should have the most distinctive effect on flora and vegetation. On the other hand, the subalpine-alpine borderline locally may coincide with the maximum extent of pleistocene valley glaciation.

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The Upper Limit of Alpine Land Use in Central, South- and Southeastern Tibet

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Introduction

The author's observations were made in 1989 during a three and a half month joint Sino-German expedition to Central, Southern and Southeastern Tibet led by Prof. Kuhle, Göttingen and Prof. Xu Daoming, Lanzhou. The areas of investigation included the Nyainquentanglha Shan of the Transhimalaya, the central Tibetan Tangula Shan, the Namche Bawar which lies in the eastern high Himalaya, the East Flank of Mt. Everst which is rising up against the southern edge of the Tibetan plateau, and the North Flank of Makalu near the Arun transverse gorge. In these regions the ecumene is found at heights between 2900 and 5300 metres (asl). This paper examines the upper borders of the various forms of the settlement and dwellings and the various economic activities to which they are related in terms of their dependence on natural and climatic conditions of this area which is currently experiencing centre-periphery change (Lautensach 1952).

Nyainquentanglha Shan

Area of Study

The Nyainquentanglha mountain range (29° – 31° N/ 90° – 93° E) rising up c 150 km N of Lhasa streches from WSW to ENE. The main valley foreland of the SE slopes (Fig 1), which runs SE and is up to 15 km wide, follows the fault line of the Yainbachen rift. In the area studied the main valley floor lies at 4600–4800 m asl. Along this valley runs the Lhasa-Golmud highway.

The Nyainquentanglha is the main watershed of the Tsangpo catchment area. The subsoil in the main valley is covered with layers of ground moraine interspersed with roches mountonnées (Kuhle 1990, p. 21). The density and the resultant impermeability of the boulder clay of the ground moraine causes excess wetness in the soil during the summer monsoon rains.

With an average plateau height of 4600 m this region lies above the tree level in the zones of periglaciation and nivation. The freeze-thaw processes, which are especially active geomorphologically at the beginning and the end of the summer, reach the highest area of the ecumene.

In a tributary valley of the S slope of the Nyainquentanglha with continuous vegetation cover solifluction phenomena are found as high as 5100 m and forms of active grass banked solifluction at up to 5250 m. These include especially earth hummocks and waterfilled hollows which develop from dammed-up water in the monsoon-influenced summer months and which characterise the gentle slopes with their small turf undulations. Above 5350 m the lack of vegetation cover encourages frost weathering. Nival forms are found at heights over 5700 m, which is also the climatic snow line. The mouths of tributary valleys are often blocked off by late-glacial moraines up to 200 m in height.

Vegetation

The SE slope of the Nyainquentanglha, lying in the zone of the high cold steppe (Chang 1981, p. 39), mainly consists of *Stipa purpurea* which characteristically gives total ground cover up to 5100 m. Some badly degraded shrubs, such as *Potentilla fruticosa, Garagana versicolor* and juniper species are interspersed with the steppe vegetation. Above 5100 m cushion plants *Arenaria musciformis, Androsacae tapete* and *Oxitropis chiliophylla* colonise the Kobresia alpine meadow until the vegetation limit at 5300 m. According to Zheng (1983, p. 39) this combination of flora on the S slope of the Nyainquentanglha is one of the Tibetan geo-elements. Because of the short summer growing season and the adaptation to frost in winter the grasses grow only slowly with small fields. However the quantity is compensated by a high quality as the alpine plants combine high nutrient content with high protein content (Wenxiu 1987, p. 3).

The weather during the Expedition

The S slope of the Nyainquentanglha lies under the influence of the monsoon which decreases towards the NW. Mean temperatures in the warmest month are 8-9 °C, the annual precipitation lying between 300 and 500 mm (Flohn 1958, p. 285). At the time of the observations between 11.08.89 and 15.08.89 the weather was characterised by low direct radiation rates of less than 100 W/m^2, by thick cloud cover at several cloud levels, and by high levels of relative humidity (70–95%) at daytime temperatures of 8 °C at 5100 m and nighttime temperatures in the region of 1-2 °C which rarely fell below freezing. As well as continuous rain the freshening wind would bring severe hail showers in the afternoon.

The Ecumene

Because of climatic and relief conditions the economic activity of the local inhabitants is limited to using the plentiful grassy alpine meadows as high pasture. For this reason the Nyainquentanglha is characterised exclusively by livestock grazing which facilitates exploitation of the boundary of the ecumene right to the upper limit of vegetation at 5250 m. Consisting of a large tent (c 48 m^2) with exterior walls (Fig 2), a stonebuilt house with turf roof and livestock pens, the herders' settlements are found on the remains of moraine terraces or on alluvial cones which have spread out from the tributary valleys on to the broad main valley floor. The quasi-stationary settlement of tents and permanent huts as described here is repeated within the study area a distance of c 4 km, mainly on S-facing slopes. Examination of a S-facing side valley showed grazing to have taken place shortly before the observation period up to 5250 m. At 4900 m a temporary camp had been left, around which were spread the camp grazing grounds.

The pastoral economy followed by the herders is based on keeping sheep, goats, dzoos, yaks and a few horses. These working animals are physiologically adapted to the highland conditions and allow effective economic exploitation by the population. Besides wool, meat, leather and milk the yak provides the traditional resource still used today for fuel.

Sheep and goats greatly outnumbered the larger animals. The danger of trampling on the gentle slopes made unstable by heavy moisture content is lessened by the smaller body weight of the smaller livestock. With the increasing tendency towards larger numbers of bigger animals because of higher meat prices and more intensive farming the threat from trampling will be increased by the greater weight as will the destruction of the valley slopes. Peat forms in the depressions between the gently undulating ground moraine on the main valley floor. In addition the grazing quality is reduced by the very high numbers of the calling hare *(Ochontona curzioniae)*. This creature undermines the surface of the ground, digs holes in it and eats away the root systems from below (Fig 5). Its spread is limited to below 4800 m.

It is important to point out that neither a vertical nor a horizontal division of economic types is found here. This is based on the uniformity of relief which hardly alters for great distances along the Yainbachen rift valley and the fact that crossing the Nyainquentanglha is only possible at a few passes.

Tangula Shan

Area of Study

The Tangula Shan (32° 05′ N/91°-92° 25′ E) rises above the landscape of the Tibetan central plateau with summits on average at 6100 m asl. The glacially moulded relief of the Tangula Shan piedmont area is characterised by a compartementation of undulating and striated rock surfaces with lakes formed between them, extensive fields of roches moutonnées, young gravel beds and rounded summits. Post ice-age periglacial weathering action gives an additional softness to the relief otherwise little dissected by fluvial processes. In the SE piedmont area of the Tangula Shan, with valley floors at 4800 m, summits reach 5300 m. The glaciation of the main peak of the Tangula Shan (Geladaindong 6621 m) descends to 5300 m. In the study area the orographic snow line lies at 5600 m (Kuhle 1989b, p. 16) on a NE facing slope. Glacial advances of historical and neoglacial periods have left behind a glacier tongue basin in the foreland up to 1000 m across and 2000 m long at a height of 5350 m (Fig 3). At the snout of the Geladaindong NE glacier massive ice pyramids have melted out marking the former extent of the glacier as blocks of dead ice and generally serving to indicate the effects of the high subtropical radiation combined with the great altitude above sea level (Fig 4).

At 4800 m the depth of thaw in the permafrost was 2.78 m and at 5350 m was 0.4 m (Kuhle 1989b). The existence of permafrost, high level summer precipitation and of meltwater lead to waterlogging and peat formation on the till-covered valley floor. Earth hummocks and hollows formed under these conditions in the zone of (relict) grass banked solifluction the SE piedmont area of the Tangula Shan reach a height of 5150 m and in the glacier tongue basin of the Geladaindong main glacier they reach 5300 m (Fig 5). On the windward S-facing slopes of the Tangula Shan foothills the stages of limited solifluction extend 50-100 m higher up the dissected slopes than on the undissected N-facing slopes on the leeside. The existence of an area of snow on the S-facing slope suggests that at the time of observation (20.08.89) the influence of precipitation was greater than that of radiation. Solifluction terraces up to 15 cm high are common up to 5050 m where trampling by livestock has loosened the turf. Slope instability is increased by the calling hares (Fig 5). Above 5350 m the vegetation stops, with frost equilibrium slopes and stone stripes characterising the scree zone.

The Vegetation

In terms of flora the Tangula Shan represents a transition zone between the high cold alpine meadow zone in the E and the high cold steppe zone in the west bordered by the 400 mm p a annual isohyet (Chang 1981, p. 39). The easternmost of the Tangula Shan receives annual precipitation of 400–700 mm p a (Zheng 1983, p. 39) which advances through the meridional gorges of the Yangtse with an influence weakening from the SE to the NW. The W part of the Tangula Shan and the NW plateau receive less than 400 mm p a and belong to the high cold steppe zone of the Tibetan flora (Zheng 1983, p. 37). The vegetation cover becomes sporadic at 5050 m and the limit of vegetation is reached at 5300 m.

The Weather during the Expedition

An automatic weather station made by Lambrecht was installed in an exposed position at 5260 m on a scree bed covered by alpine meadow on Geladaindong. For the observation period of 22. 08. 89 to 02. 09. 89 the data shows values for direct radiation between 1020 W/m^2 and 1300 W/m^2 (hand measurements on cloud free days. The degree of cloud cover was for the observation period between 6/10 and 8/10; only on five days was the cloud cover low at 2/10. Mean daily maximum temperatures at 1.5 m above the ground were 4.7° C. Daily variations lay between 6° C and 10° C. For the recording period the mean temperature was 1.65° C. High mean values of relative humidity of 74.52 % exist in conjunction with the penetration of moist southeasterly monsoonal air masses. The minimum relative humidity measured 29.6 %. Air pressure at a height of 5260 m varied according to the time of day between 517.5 and 525.5 hPa. The wind was generally from the NE, that is up the valley, with a maximum speed of 8.8 m/s. Average wind speed was 2.1 m/s. Frequent precipitation as snow or a mix of snow and hail resulted in a total of 16 mm of precipitation from 18. 08. 89 to 29. 08. 89. Eastern Central Tibet which lies above the tree line belongs to the climate classification ETH or EF according to Köppen. A wet season in summer with mean temperatures in the warmest month below 10.5° C contrasts with a cold dry winter.

Boundary zone of the Ecumene

The upper edge of the ecumene in this study area was found in the neoglacial glacier tongue basin of the Geladaindong at 5300 m (33° 26 ′ N/91° 10′ E) (Fig 3) where the well sedimented subsoil is covered by vegetation adapted to the cold and wet climatic conditions (peat moss, earth hummocks and hollows). The livestock rearing, which is here the exclusive economic activity of the tent-dwelling herders, affords a summer use of the high alpine pasture. Giant herds of yak, sheep and goats of several hundred animals are herded communally by three families in the area studied. The c 12 m^2 floorsprace of the tents suggests a transportable habitat. In the foothills of the Tangula Shan were larger camps which were often fenced in. Situated in sheltered deep valley sites up to 4900 m asl surrounded by 5400 m summits these sites provide winter grazing. Assuming that the stability of the dwelling types gives a clue as to the frequency of site relocation (Ekvall 1968, p. 33), it would seem that here a horizontal division of settlement forms is dominant which results from the move from summer to winter grazing. The Chinese 1:100000 map shows that in some tributary valleys of the Tangula Shan foothills the nomads even stay for up to one year. Obviously sufficient pasture is available. For covering large distances in areas inaccessible to trucks yaks are indispensable pack animals (Fig 6). Here too the quality of the pasture is reduced by the dampness of the soil, the formation of earth hummocks and hollows and a large population of calling hares. If a change in camp location is too late or if the grazing is overstocked due to increased livestock numbers the regeneration of the meadow is endangered because it is the young shoots which the animals prefer. Ponds which have formed in damp depressions on the slopes are worn and extended by trampling which leads to reduced vegetation cover.

Namche Bawar

Study Area

Towards the SE the character of the Central Tibetan landscape changes dramatically. The characteristic alpine glacial landscape of the Tibetan high plateau is lost with the decreasing altitude towards the SE where the morphology is increasingly dominated by fluvial processes. The ice streams of the Pleistocene drained along the Tsangpo rift, which narrows to a gorge beneath the N flank of the Namche Bawar at 29° 39′ N/94° 57′ E where it begins to breach the high Himalaya (Kuhle 1989). The morphology of SE Tibet is characterised by a high relief intensity of 4700 m which results from the altitude of the catchment area (Namche Bawar 7782 m) and the erosion base of the Tsangpo (2900 m). In the Namche Bawar area at the 'Pai' settlement (29° 35′ N/94° 55′ E) the Tsangpo flows in a 30-50 m channel. Lateral moraines follow the line of the river at 3550, 3350 and 3200 m. At 3060 m the Tsangpo has cut 60-100 m into the glaciofluvial gravels of the ground moraine. It is on this expansively formed terrace surface that settlement is concentrated. The massifs of the Namche Bawar (7782 m) and the Gyala Peri (7284 m) dominate the Tsangpo catchment area where high precipitation often causes mudslides (Fig 7). Alluvial (gravel) fans of great size have regulated themselves to the level of the Tsangpo. The steep valley slopes are forested up to 4400 m and dissected by deeply incised valleys, the scree zone lying above 5000 m. The tongue of the Namche Bawar W glacier cross the upper forest limit and end at 3900–4100 m. The orographic snow line is found at 5200 m on the W-facing slopes.

The Vegetation

As well as the change in relief the vegetation points to a centre-periphery landscape change. The upper gorge of the Tsangpo belongs to the region of Sino-Himalayan flora (Zheng 1983, p. 42). Under the influence of the S monsoon the forest zones of the S and E are integrated in the Tsangpo transverse gorge. In the study area on the NW slope of the Namche Bawar the forest stand consists of a mixed deciduous woodland with conifers at an altitude of 3200 m. The main species in the lower montaine forest zone are *Pinus likiangensis, Pinus densa, Quercus aquifoliodes* (Chang 1981, p. 37). Distinctive beard moss *(Usnea)* and vegetation with mosses and lichens on exposed moraine blocks are indicators of high humidity and precipitation. But at this altitude there is also birch, partially grouped with 3-5 m high bamboo. The next altitudinal zone of 3200–4000 m is dominated by dark coniferous forest the top edge of which is increasingly made up to *Abies spectabilis* with Rhododendron undergrowth. The quantity of *Betula utilis* was very high on the moraine slopes of the Namche Bawar W glacier up to 3900 m. After that came stands of larch which occupy the highest parts of the lateral moraine up to 4000 m. The upper boundary of the woods at 4300–4600 m is mostly juniper (Chang 1981, p. 37). Rhododendron form the transition to the alpine meadow zone which as altitude increases is covered with *Kobresia angusta* and *K. pygmaea* and reaches its upper limit at 5000 m. In the immediate vicinity of settlement forest is replaced by thorny scrub vegetation on moraine slopes.

The Weather during the Expedition

During the observation period from 09. 09. to 24. 09. 1989 the weather was characterised by a high degree of cloud cover and several periods of heavy continuous rain. In two days (17-19. 09. 89) 53 mm of rain fell. The area in the zone of condensation between 3200 and 3800 m is characterised by lush woodland vegetation. With a high degree of cloud cover hand measurements at 3160 m gave daytime temperatures of 12-15° C, 22.9° C with clearer skies. The maximum temperature reached 30° C, the minimum temperature being 9° C. During the observations there was no night frost at 3160 m. Relative humidity lay between 75% and 95%. The minimum value was 52.1%. The long periods of high intensity precipitation clearly indicate the monsoonal influence which reaches SE Tibet via the meridional stream cut valleys. Also the snow supply to the warm-temperate glacier is connected to the summer monsoon which falls above the snow line as solid precipitation. The heavy lichen cover on the large boulders similarly points to a minimum precipitation of 1000 mm p a. Because of the cloud cover which reduces insolation the diurnal temperature variation in September is small. For this reason the meltwater flow from the Namche Bawar glacier is also small as the surface moraine of up to 1 m in thickness covers the glacier snout and protects it from ablation.

The climatic station at Nyingchi at 3000 m lying W of the Namche Bawar shows a humid season between April and September which reaches its peak in June. These six humid months give a subhumid climate which shows oceanic characteristics with mild winters and warm damp summers.

The Boundary of the Ecumene

With the landscape described above the settlement and dwelling forms change. Related to this a dividing line can be drawn for the area of study between the plateau and SE Tibet along the Min La pass (ENE of Lhasa, 29° 49′ N/92° 20′ E). At 29° 53′ N/92° 39′ E in the upper Nyang-Chu valley can be found the E extremity of the flat roof construction used in the valleys by the mainly arable farmers and by the nomads above the limit of cultivation at 4000 m. East of the watershed in the Min La pass the saddleback roof replaces the typical flat mud roof of the Tibetan uplands which is suited to the dryer conditions there. The settlements along the sharp bend in the Tsangpo near the beginning of the breach (29° 35′-38′ N/94° 55′-57′ E) at 2900–3160 m should be regarded as typical examples of SE Tibetan settlement. The settlements are mainly situated out of the reach of floods on the youngest glaciofluvial gravel terraces which stand 60-100 m above the Tsangpo or on the alluvial fans scattered on the gravel terraces.

The two-story houses (Fig 8) are made of stone and wood. The shingle saddle roof, constructed by purlins, rests on the masonry of the supporting ground floor. The use of shingles is related to the extent of distribution of conifers *(Larix, Abies, Pinus)* while in the area near crystalline slate in the Nyang-Chu valley (29° 53′ N/93° 15′ E) slates are used for roofing. The two storeys are divided from each other by a wooden floor carried on beams resting on the supporting walls. The upper storey, reached by an external tree-trunk ladder, is used for storing grain and straw. The gable ends of the roof are often open and on the long side there are often open gaps between masonry supporting posts and roof joists which are filled with straw. The closed facades which Kleinert (1983, p. 168) reports for the East Nepalese houses on the monsoon wet S slope of the Himalaya as an adaptation to the seasonal climate changes are also found in this area. The saddle roof construction is functionally suited to the summer monsoon.

The settlements in the region of the Tsangpo transverse gorge lie in the middle of the open fields (Fig 7). The cultivated area is divided up into irregular blocks of scattered parcels and is separated from the area lying fallow which is grazed. Precipitation falling during the growing season makes rainfed cultivation possible. Good drainage is provided by the finely divided minerals of the sand-clay fraction of the alluvial terrace gravels. The individual field divisions are surrounded by apricot and apple trees whose fruit provide food for people and livestock alike. One cow consumes about 20 apricots in one digestive cycle. For human consumption the apricots are dried and preserved.

In mid-September some fields are tilled; thorn thicket keeps the free ranging cattle from the tilled fields. Buckwheat is harvested between 2900 and 3000 m with potatoes as a late crop on the higher terraces at 3650 m (Fig 7). Straw is laid out to dry on specially constructed wooden platforms in the fields. Wheat is threshed on communal village threshing floors and is milled in the water-mills near the settlements.

The three settlements visited by the authoress, which are on the orographic right bank of the Tsangpo as far as the gorge, are joined together by a narrow mule track up to one pack horse wide and fall away precipitously on the river side. The path is often buried by mud slides or avalanches which then temporarily interrupt the contact between the settlements. One assumes therefore that the economic basis of a village is sufficient to last the winter. After 3-4 hours walk on the way between two settlements down river one passes grazing gates which mark a boundary for grazing in the woods.

The zone of economic activity does not exceed or extend to the tree line, which is therefore not influenced by human activity and it seems there is a balanced relationship between the people and the natural surroundings.

In relation to the changing settlement structure nomadic livestock rearing is decreasing in importance as an economic acitivity. The distribution of the nomads is limited to the upper Nyang valley. The majority of nomadic herders were camped together in groups of three, five or eight from the beginning to the end of September W of the Min La pass at altitudes between 4600 and 4700 m. Along the Nyang Chu as far as the gorge of the Tsangpo the use of the valley terraces is based on agro-pastoral farming with the emphasis on arable farming. The working animals (mostly dzoos and cattle) are kept for arable use. In the areas below 3000 m pigs and chickens are also kept.

South Tibet in the catchment area of the Arun as far as the East Flank of Mt. Everest

The area of study

The observations extend over the tributary valleys of the mid and lower Arun, the Dzakar Chu, Kharta Chu and Kama Chu, which run directly across the regional drainage direction. The Arun is a transverse through-flowing river which flows across the Tibetan border mountains and begins its gorge section through the central high Himalayas a few kilometres below the confluence of the Kharta valley. The landscape is characterised on the one hand by the rounded erosional landscape of the Tibetan Himalayas shaped in the ice age and subject to recent major fluvial incision, and on the other hand by the towering high Himalaya with deeply incised valleys and glacial deposits of prehistoric to recent times.

By the time it joins the Arun the middle Dzakar Chu (28° 23′ N/87° 02′-24′ E) shows a maximum relief intensity of 1500 m with a valley floor altitude of between 4100 and 3800 m and average summit heights of 5600 m. The gentle slopes show heavy hillwash and gullying which points to fluvial incision of the surface of the slopes which have only a thin protective cover of vegetation. Alluvial fans lying on the gravel filled valley bottom have 20-30 m deep incisions. The rock has been shattered by recent and subrecent frost-splitting because of the alternating quartzite and softer sediments (Kuhle 1989b, p. 27). Frost shattering occurs above 5000 m. The Dzakar Chu joins the Arun which then flows S for 25 km cutting down 50-100 m into the ground moraine which fills the valley floor.

The Kharta Valley (28° 08′ N/87° 17′-20′ E) shows glacial formation for the whole valley. The meltwater river from the Karze glacier has cut 80-100 m into the glacio-fluvial gravel terraces. The link between the parallel longitudinal valleys of the Kharta and the Kama is formed by transfluence passes of which the Tsao La

Fig 1 The main valley foreland running SE of the Nyainquentanglha, up to 15 km across, reaches a height of 4600–4800 m in the area of study (30° 12′ N/90° 30′ E). During the monsoon the solifluction earth hummocks and hollows are welldefined in the transitional zone from bound to limited solifluction up to 5200 m. The mountain ridges on the orographic right are covered from fresh snow above 5800 m, meltwater streams cut through the valley floor covered with gently undulating ground moraine with roches mountonnées. A dzong is erected above a nomad camp at 5100 m.
Date 10. 08. 89, Photo M. Kuhle

Fig 3 Glacial advances from the neoglacial to the historical period in the Geladaindong/Tangula Shan (33° 26′ N/91° 10′ E) left a broad glacial trough foreland which is here at 5300–5350 m. Dammed up water results in the formation of peat bogs and small ponds (up to 2 m across). This is the upper limit of alpine land use, which at the time of observation was being grazed by the livestock of three nomad families camped here (some 400 sheep, 150 yaks and goats).
Date 23. 08. 89, Photo S. Meiners

Fig 2 A herder's tent, c 48 m^2, on the S slopes of the Nyainquentanglha at 4850 m and surrounded by a retaining wall. At the entrance of the tent stands a herder in the typical coat held together with a decorated clasp. In the background the alpine grassland is only found on the level ground, having been broken up on the steeper slopes by livestock trampling.
Date 15. 08. 89, Photo S. Meiners

Fig 4 NE-facing tongue end of the Geladaindong main glacier melts into pyramids of ice because of the high subtropical radiation and the height of above 5000 m asl. The glacier snout borders the highest zone of human economic activity. A drop of 500 m in the ELA (Equilibrium Line Altitude) would eliminate the highest pasture zone from use.
Date 24. 08. 89, Photo S. Meiners

Fig 5 In the zone of bound solifluction at 5050 m there are commonly solifluction terraces with steps up to 15 cm in height (33° 28′ N/91° 57′ E). The vertical faces of the terraces give easy inlet for calling hares and marmots which eat away the roots from below. The combination of solifluction, undermining and trampling leads to slope instability and features of slope disintegration.
Date 19. 08. 89, Foto S. Meiners

Fig 7 Hamlets on a lateral moraine terrace in an orographic right bank tributary valley of the Tsangpo at the foot of the Namche Bawar at 3550 m asl. The edge of the terrace drops steeply down to the valley 300 m below. The land is divided into regular blocks under mixed crops. In the background on the thickly wooded slopes can be seen fresh mud slides resulting from the steepness of the relief and the high saturation.
Date 11. 09. 89, Photo S. Meiners

Fig 6 The yak is indispensable as a pack animal and form of transport for covering large distances away from the few main transport routes (Lhasa-Golmud highway) in the interior of the central Tangula Shan because heavy vehicles can only travel under the most difficult conditions on the trackless morasslike ground. A pack-saddle is needed for carrying loads. Some yaks are also used for riding.
Date 20. 08. 89, Photo S. Meiners

Fig 8 Form of a SE Tibetan house with a saddle roof on a main settlement terrace at 3120 m on the orographic right of the Tsangpo (Pai village, 29° 35′ N/94° 55′ E). The shingle saddle roof rests on the masonry of the supporting ground floor. Front and rear of the roof are open to allow the harvest and straw to be stored. Firewood is stored piled up on the wall made of boulders.
Date 17. 09. 89, Photo S. Meiners

Fig 9 Small lateral moraine valley at 5200 m on the orographic left of the Kangchung glacier valley. The sheltered valley has a glacial stream running through it and lies immediately below the highest accessible nomad camp and grazing area on the E flank of Mt. Everest, which towers up in the background. At the time of observation from mid to late October 1989 the alpine pasture between 4400 and 5200 m was not being used by the herders. Date 13. 10. 89, Photo S. Meiners

Fig 11 Irrigated cultivation on alluvial gravel fan in the dry lower Arun valley at the confluence with the Kharta valley at 3700 m asl (28° 08′ N/86° 20′ E) in the rain shadow of the high Himalaya. Date 6. 10. 89, Photo S. Meiners

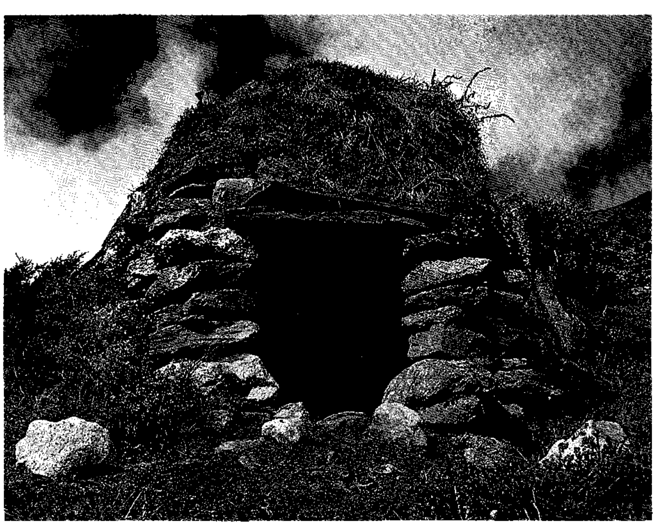

Fig 10 Storage huts (wood stores) on an alp at 4900 m on the orographic left of the Kangchung glacier valley. The huts 1.7 m across and sunk 40 cm into the ground do not permit standing up in comfort or enough space to lie down comfortably so the explanation as storage huts is probable. A 1 m thick turf layer covers the roof made of slabs of slate. Date 13. 10. 89, Photo S. Meiners

(4900 m) and the Langma La (5100 m) are accessible. The transfer to the Kama valley is via a 400-600 m confluence step which forms the end of the glaciated valley running towards the S. This valley is characterised by rocks from boulders to house-sized blocks and mud-slides stretching down below the tree line.

The tributary streams running from the glaciated flanks of the peak of the Chomolönzo-Makalu-Lhotse Wall (7465–8872 m) and the E flank of Mt. Everest merge in the Kama valley (28° 06′ N/87° 05′-20′ E). The Kama valley is glaciated down to 3850 m. The longest tongue of the Kangchung Glacier at 18.5 km comes from the Everest E flank and ends at 4520 m. The climatic snow limit on the N-facing slope of the Himalaya lies at 5630 m, the orographic snow limit of the Himalaya Glacier being between 5800 and 5900 m, so the nevé (firn) field at 5200 m is fed by ice avalanches.

On the orographic left of the Kanchung glacier valley lateral moraine terraces of up to 400 m in width and various heights rest against the valley sides, interrupted by smaller and larger valley-side troughs (Fig 9). In the Kharta and Kama valleys the periglacial zone extends between 4200 and 5600 m. Assuming an annual median temperature in S Tibet of 5-6° C at 4000 m, the 0° C isotherm lies between 5000 and 5500 m which means that the number of freeze-thaw days is greatest at this altitude. On the valley slopes of the lateral moraine terraces with closed vegetation cover up to 4800 m, a down-slope movement is obvious from the rolled up turf on the faces of the terrace steps. At 5600 m the frost shattering/scree zone begins. In the tributary valleys orographically to the right above the area of settlement in the Kharta valley a zone of limited and free solifluction up to 4200 m could be discerned (N slope of the Tsao La). Above that comes a zone (up to 4500 m) of bound solifluction which changes to a zone of limited solifluction again near the pass at 4800 m.

The Vegetation

The high Himalaya forms a climatic divide between the semi-arid Tibetan Himalya with 50-60 % of its flora from typical Tibetan species and the damp monsoonal S slopes predominantly of the Sino-Himalayan flora (Zheng 1983, p. 45). The valley slopes of the Dzakar Chu were sporadically covered by steppe grass and grazing-resistant berberis; this is the altitude zone of the temperate steppe (Chang 1981, p. 40).

In the zone of the high cold steppe (above 4400 m) steppe grasses *(Stipa purpurea)* and occasional bushes *(Caragana versicolor, Potentilla fruticosa)* are found (Chang 1983, p. 43). The upper limit of vegetation is reached at 5000 m. Poplar *(Populus)* and sea buckthorn *(Hippophae rhamnoides)* grow along the watercourse of the Dzakar Chu. The vegetation of the lower courses of the Kharta and the Kama points to the climatic transition from the semi-arid to moist monsoonal milieu on the S slopes of the Himalaya. Dense woodland covers the valley slopes of the sub-alpine zone up to 4200–4300 m. The edge of the woodland is made up of birch, juniper and rhododendron reaching here a height of 4 m and covered in beard lichen *(Usnea)*.

Between the precipitation limit and the temperature limit the vegetation of the N slopes of the Tsao La forms lush ground cover in the condensation zone (4500–4800 m). Up to 4600 m the juniper stands are pruned regularly. Different types of rhododendron dominate the steep slopes of the S face of the Tsao La. Up to 5300 m October gentians (10.10.89) and primula species are interspersed with sparse alpine vegetation.

From 5400 m the vegetation cover breaks up. On S-facing slopes the upper limit of vegetation is formed by cushions on the edge of a glacial lake in 5600 m in the valley of the Kangchung glacier. The nomads' camps were surrounded by grazed fields of grazed flora. Because of the favourable climatic conditions the valleys of the Dzakar Chu and the Kharta Chu in the temperate steppe are suited to irrigated grain production while the altitude of the high cold steppe and the alpine meadows, particularly in the Kama valley above 4300–4400 m, means only grazing is possible.

The Weather during the Expedition

A weather station (Lambrecht, Göttingen) was set up on a lateral moraine at 5250 m in the valley of the Kangchung glacier and the data for the period from 15.10.89 to 23.10.89 can be summarised as follows. Air temperature was on average -7° C to -9° C with a maximum value of -1° C and a minimum value of -14° C. Relative humidity from 15.10.89 to 23.10.89 was on average over 90 %, otherwise sinking to 55.24 % to 85.7 %. The minimum was 25.6 % Level of cloud cover was generally high. The clouds came up the Arun transverse gorge up to the upper Kama valley from the S and E. Radiation reached a maximum of 1020 W/m^2, reflected radiation a maximum of 363 W/m^2. Despite the high level of cloud cover only occasionally were there periods of heavier precipitation. The air pressure varied between 470 and 513 hPa.

The data for the period in October 1989 can be classified with the climate diagram of Tingri (4300 m) which is typical for S Tibetan climatic conditions. Mean monthly temperatures in the warmest months of July, August and September reach 10° C when there is also a humid season with a mean whole-year precipitation of 300-500 mm. The climate diagram for the station at Jatung (2987 m) in the northern section of the E Himalayan central range exemplifies the effect of the Arun transverse gorge on the drier N side of the high Himalaya. Here annual precipitation reaches 957 mm. With precipitation all the year November is the driest month and the main period of precipitation is between April and September.

With average annual temperature of 8.1° C the lower Kharta and Dzakar Chu lie in the BSK'w region, a steppe climate with dry winters, while the zones above the tree line belong to the ETH climate. Jatung, with its dry-winter 'Sino' climate, belongs to the Cwb climate.

Boundary Zone of the Ecumene

The relatively high density of settlement in S Tibet (10 inhabitants per km^2, according to Karan 1976, p. 54) points to a favourable region which allows cultivation up to the altitudinal limit and, moreover, offers sufficient pasture in the alpine and subnival zones. The agricultural settlements, or hamlets (according to Niemeyer), of the Dzakar Chu and the Kharta valley are situated in the middle of the irrigated fields on the fluvioglacial gravel terraces which in the Kharta valley nestle close to the valley slopes and only provide enough space for seven hamlets at intervals of 1.5 km. From the method of construction of the typical Tibetan houses (Kleinert 1983, p. 192) one can estimate 4-5 units of accomodation per hamlet in the Kharta valley. The solid construction method is characterised by tapering cube-built stone walls with a flat mud roof. The flat roof is related to the semi-arid continental climate of the Tibetan Himalaya. The limited extent of the settlement allows for an optimal exploitation of the spatially restricted economic zone. Provisions are piled on the top of the flat roofs and yak dung, firewood and hay are laid out to dry. During the day the solid walls store up the heat from the sun and release it into the house interior with a delay of eight hours, depending on the retentiveness of the material (Kleinert 1974, p. 362). Occasionally narrow window slits are built into the walls. The paths between the settlements are lined with Tschörten (containers of relics). Immediately outside the hamlet there is often a carefully fenced in area of woodland which is not cleared and may well be of religious significance. Connected with this there also earth mounds in the freshly ploughed fields of the Kharta valley and in the area around Lhasa with small white stones placed on them. These are probably offerings to the 'earth-spirits' which are injured by the plough during cultivation (Lehmann 1981, p. 154), and is probably a relict from the pre-Buddhist Bön religion according to which spirits can lurk behind every rock, bush or tree.

The economic foundation of the inhabitants of the deep valleys is based on a form of mixed economy which Clarke (1987) describes as Agropastoralism. Arable cultivation which dominates is supported and expanded by limited livestock rearing. The fields are either on the narrow glacio-fluvial gravel terraces, as for example in the Kharta valley or the Dzakar Chu, or laid out on the terraced hillsloppes or alluvial fans (Fig 11). Because of the semi-arid climate the fields, with one exception near Shigatze in the Tsangpo valley, are irrigated (Haffner 1981).

The cereal crop on the Tsangpo is well enough advanced by October for threshing to begin everywhere. Threshing is done by hand or by donkey or the grain is laid out on an asphalt roadsurface and the trucks driving past thresh the grain. In the dry lower Arun valley the livestock is mainly goats and sheep. In the Kharta valley dzoos and yaks are kept along with a large number of goats. In addition to the grain harvest the activities of the population of the Tsangpo at the beginning of October include bringing in the winter hay. In the area around Lhasa (10 km to the N) terraced fields located at the upper limit of cultivation and difficult to work were often abandoned and with the terraces neglected this leads to increased erosion.

On the alluvial land along the Lhasa He river are extensive areas of vegetable monoculture to supply the growing needs of the expanding city of Lhasa. Above the economic zone of the agropastoralists the herders use the alpine meadows which cover 51.51 % of the land of Tibet between 4700 and 5200 m (Honglei Sun 1983, p. 145).

In Central and S Tibet the boundary between herders and agropastoralists lies between 4400 and 4600 m. While the highest permanent settlement on the N side of the Tsangpo is at 4650 m, there are nomad camps up to 5150–5250 m. In mid-October there were seven nomad households camped between Shigatze and Tingri at 5150 m. At the time of observation the broad lateral moraine terraces on the orographic left bank of the Kangchung glacier valley at 4400–5200 m were not occupied.

On the Pethang Ringmo alp (4700 m) as well as at the next higher camp at 4900 m in the Kangchung glacier valley there were permanent storage huts (Fig 10). They were circular huts with a diameter of 1.70 m sunk about 40 cm into the ground and constructed of boulders up to waist height. A strong 1 m thick layer of turf covers the slate slabs which form the roof. According to a Tibetan accompanying the expedition these storage huts are used specifically for wood storage. The necessity for having a wood storage suggests that the distance to the nearest place for collecting wood is too great should the weather break. Also one can assume that it is not sufficiently dry during the summer grazing period to dry out the yak dung and provide enough fuel. Next to the permanent huts the alpine camps could be discerned from the surrounding low walls for the tents, made from upright slabs of slate, and the fireplaces inside the walls constructed in the same way. From the diameter of the slate circles the tents are 2.5 m across. The number of tent circles suggests 4-6 tents per camp. The highest camp in the Kangchung glacier valley was at 5200 m, only just supplied with water. In order to maintain the pasture the moraine slopes of the Kama valley at 4350 m had their heath cover burned off to prevent the meadows from being overgrown.

In the immediate catchment area around Lhasa (c 20 km S) the economic zone of the nomads borders directly on to that of the agropastoralists. Contrary to the conditions in south Tibet the yak herds were numerous and large. In addition the farmers have a larger number of small and large livestock, all in all giving a high livestock density. It is not unreasonable to suppose that the increased meat requirements of Lhasa have led to the increased livestock numbers and meat production. That means that it is mainly male animals which are kept because of their higher portion of meat and that as a result the herds are restructured.

From mid to late October there were some trading caravans of 6-13 pack animals en route, as for example in the Latzu-La pass (28° 51′ N/87° 20′ E) on the way to Shigatze or on the old trade route from Lhasa to Kathmandu which goes over the Tsao-La (4900 m) into the Kama valley and then follows the Arun gorge south. Shelters built below the steep ascent of the pass at 4600 m indicate that the pass is often frequented. The huts are temporary with walls leaning against overhanging rock faces.

Summary

Over 65 % of the landsurface of Tibet lies above 4300 m in the subalpine and alpine zones, 21.32 % lying between 3700 and 4300 m (Honglei Sun 1983, p. 145: relating to the Tibetan Autonomous Region). As the

result of the natural division of Tibet the subalpine and alpine zone used for grazing is clearly marked off from the zones below 4300–4400 m where cereal cultivation is possible.

In the Central Tangula Shan and in the South Tibetan Kangchung glacier valley, the Kama valley and the Kharta valley the boundary zone of the ecumene can be divided into a summer grazing zone (up to 5300 m in the Tangula Shan, 5500 m in the Kama and Kharta valleys) and a lower winter grazing zone with a more favourable climate. In the Nyainquentanglha Shan this division is not present because the relief alters so little over long stretches. On the Namche Bawar the boundary of the ecumene lies at the limit of the woodland at c 4400 m. Because of the steepness of the Tsangpo transverse gorge the alpine zone is not used for economic activities.

Although the upper limit of the ecumene cannot exceed the limit imposed by temperature, the upper limit in South and Central Tibet also does not fall short of it, i. e. there is a complete exploitation of the resources of the land according to the relevant economic uses. Thus the limits of cultivation are reached at c 4400 m and there is no vertical leeway left. The boundary between cultivation and nomadic pastoralism falls in the sensitive limit of the woodland zone which is subject to widespread degradation near Lhasa, in the Tsangpo and Arun valleys because of the heavy demands placed on it (expansion of the farmed area, firewood collection). Only in the relatively inaccessible area on the Namche Bawar is the natural woodland limit retained at 4400 m, the exploited area is restricted mainly to the valley terraces along the Tsangpo because of the steepness. The pressure on the agricultural area in central and southern Tibet is very great because, due to the Chinese measures for intensification which extend the irrigated area of production such as winter wheat, on the one hand the use of legumes in the crop rotation to maintain fertility is reduced and on the other the winter grazing zone is overload by increasing livestock numbers by 25 % (Clarke 1987, p. 26).

The resultant ecological consequences culminate in the destruction of the vegetation cover in the sensitive periglacial zone by trampling from overstocked pastures, in the risk of soil erosion in semi-arid Tibet, in the wind abrasion of the cultivated areas and in the exhaustion of the soil from the increased use of fertilisers.

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