HUMIDITY CONDITIONS IN THE WESTERN KARAKORUM AS INDICATED BY CLIMATIC DATA AND CORRESPONDING DISTRIBUTION PATTERNS OF THE MONTANE AND ALPINE VEGETATION

With 9 figures (Fig. 4 as Supplement IV)

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Dedicated to PETER HÖLLERMANN on the occasion of his 65th birthday

Zusammenfassung: Feuchtigkeitsbedingungen im westlichen Karakorum abgeleitet aus Klimadaten und Verteilungsmustern der montanen und alpinen Vegetation

Laufende Klimauntersuchungen im westlichen Karakorum ermöglichen die Ableitung regionaler vertikaler Feuchtigkeitsgradienten, die mit dem räumlichen Muster von Pflanzenformationen gut in Einklang stehen. Vier feuchtigkeitsbedingte Höhenstufenabfolgen der Vegetation können unterschieden werden:

– Sub- bis semi-humide Sequenzen: geschlossene Nadelwälder der oberen montanen Stufe und geschlossene Cyperaceen-Rasen in allen Expositionen der alpinen Stufe.

– Semi-aride Sequenzen: geschlossene hochmontane Wälder und geschlossene Cyperaceen-Rasen an schattigen Hängen, offene Gehölz- und Krautformationen an sonnenexponierten Hängen.

– Sub-aride Sequenzen: offene *Artemisia*-Zwergstrauch-Gesellschaften mit Wacholder-Baumbestand in der montanen Stufe. Offene Krautformationen in allen Expositionen.

– Eu-aride Sequenzen: offene Chenopodiaceen-Zwergstrauch-Gesellschaften über die ganze montane Stufe; keine Regenerierung der *Juniperus*-Bestände; *Artemisia* spp. nur in offenen Formationen der alpinen Stufe, in der ansonsten Polsterpflanzen mit Gramineen überwiegen (alpine Steppe).

Im westlichen Karakorum verändern sich die lokal modifizierten Höhenstufenabfolgen entlang eines SW-NE verlaufenden Gradienten abnehmender Feuchtigkeit. Geschlossene Pflanzenbedeckung ist an sub- bis semihumide, in Gunstlagen semiaride Standortbedingungen während der Vegetationsperiode gebunden. Das Klassifikationskonzept wird im Verlauf weiterer Untersuchungen zu überprüfen sein.

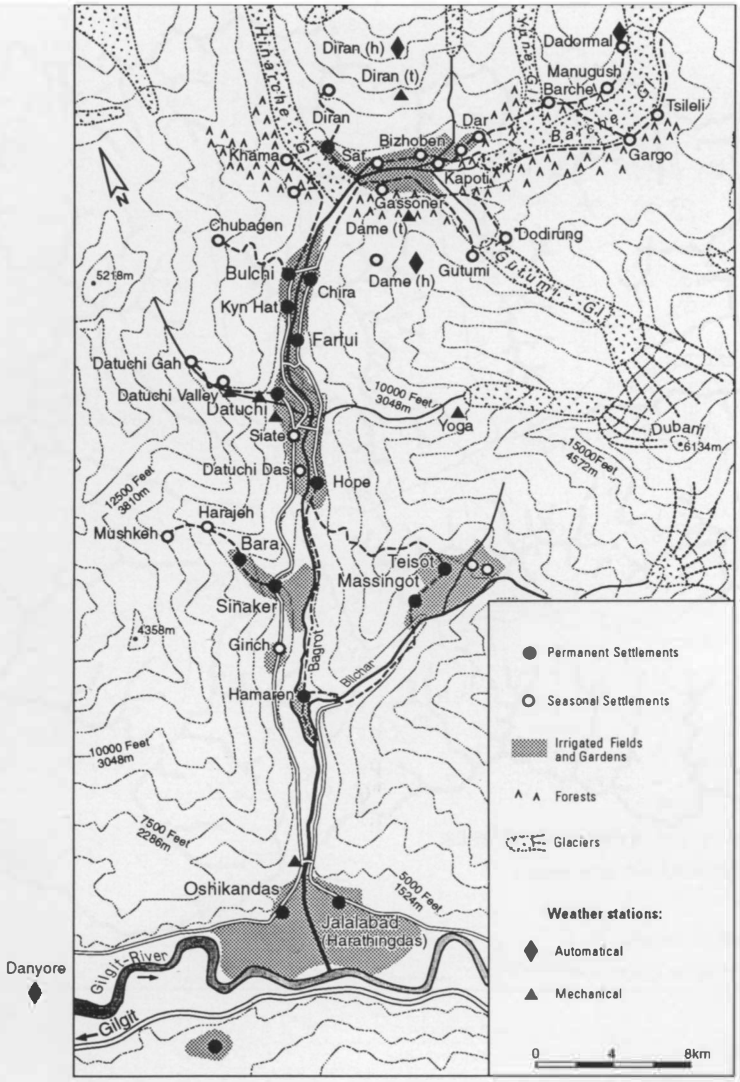
1 Introduction

When TROLL (1939) and PAFFEN et al. (1959) published the results of their outstanding research on the vegetation cover of Nanga Parbat and the Hunza Valley respectively, they concluded that a combined approach of vegetation studies and detailed topo-climatic investigations might provide the key for a functional understanding of the distinct vegetation pattern. There is strong evidence that altitudinal belts as well as topographic differentiations reflect thermal and hygric conditions which seem to be rather specific for the westernmost ranges of the Himalaya and even more distinct for the deeply incised valleys and giant mountain ranges of the Karakorum and eastern Hindukush: a vertical ecologic sequence ranging from arid valley bottoms, to semi-arid or semi-humid montane belts up to rather humid alpine and nival belts is superimposed by sharp contrasts depending on exposure. Focusing on the interpretation and explanation of this predominant ecologic pattern, we would like to discuss first results of environmental studies which are part of the Pakistan-German research programme "Culture Area Karakorum" (CAK). Detailed investigations of the topo-climatic situation are necessarily restricted to some selected case studies. In addition, however, the natural vegetation represents an indicator of those climatic factors which determine plant growth. This can be studied in all areas where natural vegetation is preserved. Calibration of these vegetation indicators by means of climate data was conducted in two test areas of the CAK (CRAMER 1994, Bagrot; JACOBSEN 1992, 1993, Yasin), which differ significantly in terms of their humidity conditions.

2 Methods of survey

2.1 Climate studies

Automatic meteorological stations were installed in the autumn of 1990 in the Bagrot valley (a northern tributary of the Gilgit River E of Gilgit) and in late 1991 in the Yasin catchment on the south-eastern slopes of NE Hindukush (Figs. 1, 2 and 9). The stations were installed along N-S and E-W profiles in order to get both vertical climatic gradients between 1500–4500 msl, as well as differences in exposures. Air temperature, relative humidity and precipitation (including snow depth) are registered at all weather stations hourly. In addition, solar and net radiation, wind direction, wind velocity, soil temperatures and soil humi-

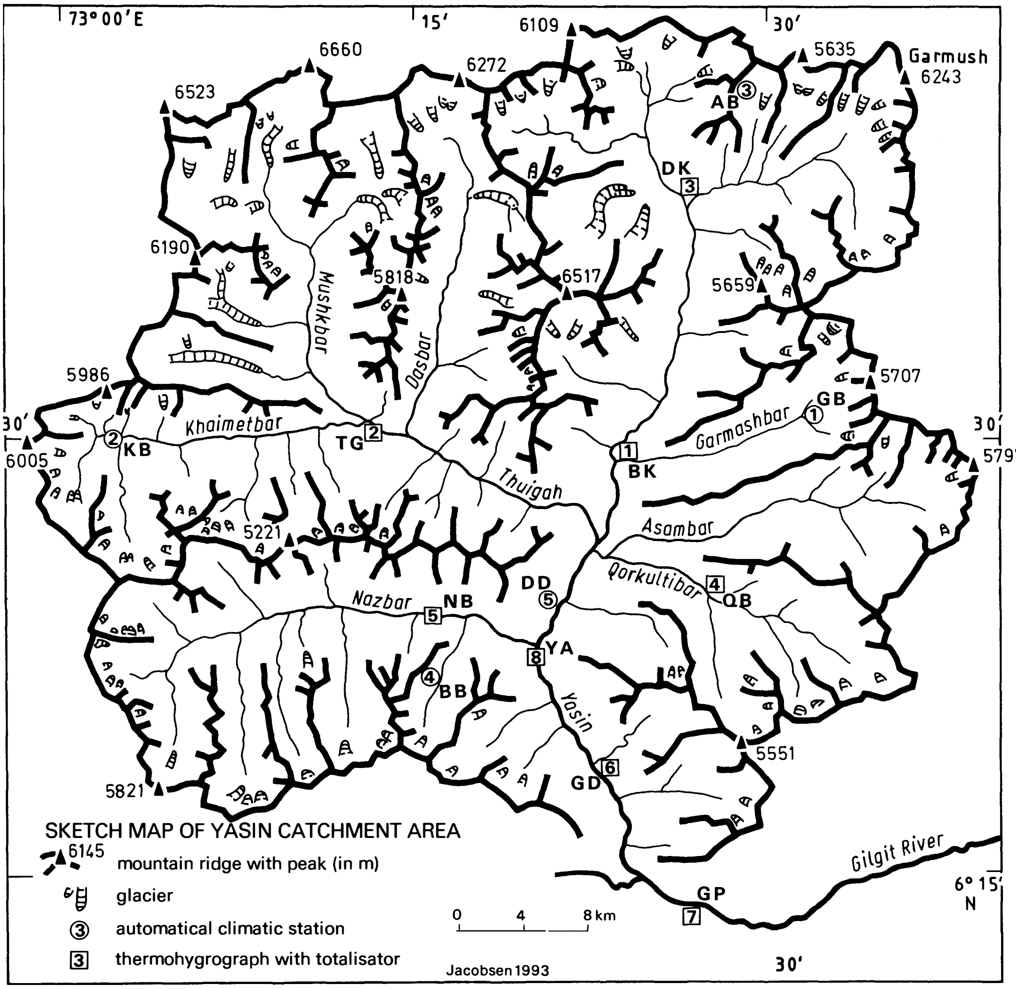


Location	Altitude	Latitude	Longitude	Type of station	at	rh	snd	p	rad	net	wd	wv	st	sm
Gilgit Airport	1460 m	35°55'N	74°20'E	Pak.Meteorol.Service	X	X	—	X	—	—	X	X	—	—
Dadormal	3560 m	36°03'N	74°40'E	Campbell CR10	X	X	X	X	X	X	X	X	X	X
Dame high	3780 m	36°01'N	74°35'E	Campbell CR10	X	X	X	X	X	X	X	X	X	X
Dame low	3220 m	36°02'N	74°35'E	Campbell CR10	X	X	—	X	X	X	X	X	X	X
Danyore	1520 m	35°53'N	74°25'E	Campbell CR10	X	X	—	X	X	X	X	X	X	X
Datuchi	2240 m	36°00'N	74°31'E	Thermohygrograph	X	X	—	X	—	—	—	—	—	—
Datuchi-valley	2960 m	36°01'N	74°31'E	Thermohygrograph	X	X	—	X	—	—	—	—	—	—
Datuchi-gah	2450 m	36°00'N	74°31'E	Thermohygrograph	X	X	—	X	—	—	—	—	—	—
Diran	4150 m	36°04'N	74°36'E	Campbell CR10	X	X	X	X	X	X	X	X	X	X
Diran low	3650 m	36°03'N	74°36'E	Thermohygrograph	X	X	—	X	—	—	—	—	—	—
Oshiken-das	1490 m	35°54'N	74°39'E	Thermohygrograph	X	X	—	X	—	—	—	—	—	—
Sat	2650 m	36°02'N	74°36'E	Thermohygrograph	X	X	—	X	—	—	—	—	—	—
Yoga	3200 m	36°04'N	74°34'E	Thermohygrograph	X	X	—	X	—	—	—	—	—	—

at = air temperature; rh = relative air humidity; snd = snow depth; p = rain precipitation; rad = radiation; net = net radiation; wd = wind direction; wv = wind velocity; st = soil temperatures; sm = soil moisture

Fig. 1: Location and type of meteorological stations installed within the framework of the Culture Area Karakorum project in the Bagrot valley

Meteorologisches Stationsnetz des CAK-Projektes im Bagrot-Tal (Karakorum): Standorte und Sensorbestückung



Location		Altitude	Latitude	Longitude	Type of station	at	rh	snd	p	rad	net	wd	wv	st	sm
Alambar	AB	4400 m	36°42'N	73°29'E	Campbell CR10	X	X	X	X	X	X	X	X	X	—
Barkulti	BK	2420 m	36°29'N	73°24'E	Thermohygrograph	X	X	X	X	—	—	—	—	—	—
Bulibalsirbar[1]	BB	4050 m	36°22'N	73°15'E	Campbell CR10	X	X	X	X	X	X	—	X	X	—
Darkot	DK	2600 m	36°39'N	73°26'E	Thermohygrograph	X	X	X	X	—	—	—	—	—	—
Didargah	DD	2400 m	35°25'N	73°21'E	Campbell CR10	X	X	—[2]	X	X	X	X	X	X	X
Garmashbar	GB	3600 m	36°31'N	73°32'E	Campbell CR10	X	X	X	X	—	—	—	—	X	—
Gindai	GD	2230 m	36°18'N	73°23'E	Thermohygrograph	X	X	X	X	—	—	—	—	—	—
Gupis	GP	2150 m	36°14'N	73°25'E	Thermohygrograph	X	X	X	X	—	—	—	—	—	—
Khaimetbar	KB	3600 m	36°30'N	73°03'E	Campbell CR10	X	X	X	X[3]	X	X	X	X	X	—
Nazbar	NB	2630 m	36°24'N	73°16'E	Thermohygrograph	X	X	X	X	—	—	—	—	—	—
Qorkultibar	QB	2950 m	35°25'N	73°28'E	Thermohygrograph	X	X	X	X	—	—	—	—	—	—
Thuigah	TG	2740 m	36°30'N	73°13'E	Thermohygrograph	X	X	X	X	—	—	—	—	—	—
Yasin	YA	2310 m	36°25'N	74°21'E	Thermohygrograph	X	X	—	—	—	—	—	—	—	—

at = air temperature; rh = relative air humidity; snd = snow depth; p = rain precipitation; rad = radiation; net = net radiation; wd = wind direction; wv = wind velocity; st = soil temperatures; sm = soil moisture
[1] = only up to 23rd July 1992; [2] = snow was measured by the raingauge; [3] = without April up to November 1992

Fig. 2: Location and type of meteorological stations installed within the framework of the Culture Area Karakorum project in the Yasin catchment area

Meteorologisches Stationsnetz des CAK-Projektes im Yasin-Einzugsgebiet (westlichster Karakorum): Standorte und Sensorbestückung dity are also monitored at selected locations[1]. As these climatic data were collected over only a few years, they are still of low statistical reliability. However, the measurements continue, with the aim of providing more representative data in the future.

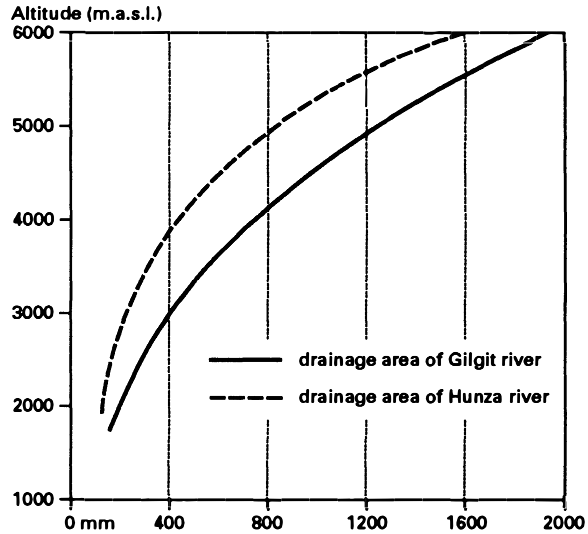


Fig. 3: Estimated altitudinal variation of mean annual precipitation in the W Karakorum (extrapolated from a digital precipitation map based on a multi-variate statistical model). Changed from WEIERS (1995)

Geschätzter vertikaler Niederschlagsgradient im westlichen Karakorum, abgeleitet aus einer Niederschlagskarte von WEIERS (1995)

2.2 Vegetation studies

Three different approaches were made within the CAK project to correlate the vegetation with environmental parameters:

1) BRAUN (1996) mapped the actual plant formations in the Hunza Karakorum by field survey and digital satellite data processing, focusing on forest distribution. Topographic and topoclimatic data derived from mapped forest relicts and from sunshine- and short-wave radiation income models provided information for the design of the potential forest distribution in the test area.

2) SCHICKHOFF (1995) studied the floristic composition and age structure of those relict forests which are made up of valuable timber trees *(Abies, Picea, Pinus* and *Cedrus),* in order to quantify the degree of exploitation/degradation. The distribution of these species in the western Karakorum and adjacent mountains is correlated with the regional moisture patterns.

3) G. and S. MIEHE undertook (1990/91) phytosociological studies of all quasi-natural vegetation types in zonal habitats from the colline to the sub-nival belt in selected test areas in the western Karakorum and eastern Hindukush. The aim is an eco-climatological classification of floristic entities and the assessment of the potential, climate-dependent distribution of vegetation belts, especially the forest belt, including the driest *Juniperus* open forests.

If the vegetation is used as an indicator of climatic humidity, it is essential to

– consider the natural or least disturbed vegetation; and

– restrict the analysis to zonal habitats (excluding sites with water surplus or edaphically dry situations).

However, the vegetation on the easily accessible zonal slopes has preferentially been transformed by grazing and woodcutting. Thus, G. and S. MIEHE (field studies 1990/91) focussed on relict patches of little disturbed vegetation in remote areas, in order to work out any climate-indicative plant species and formations. These indicators allow the potential natural vegetation in those areas where man's influence on the vegetation is stronger, to be assessed.

In the course of two 3-month long expeditions undertaken by G. and S. MIEHE in 1990/91, vegetation was studied in those areas shown in Figure 9. The hatched or dotted areas include additional information on the catchment area of the Baltoro Glacier and the eastern part of the Rakaposhi N flank studied much earlier by PAFFEN et al. (1959), the Naltar valley mapped by BRAUN (1996, and pers. comm.), the K2 area investigated by DICKORÉ (1991) and the eastern Shigar tributaries (Baltoro- and Biafo-Glacier) studied by HARTMANN (1966, 1968, 1972). SCHICKHOFF (1995, and pers. comm.) provided additional information on the upper Ishkoman valley, the Morkhun Nullah SE of Sost, the Haramosh area, the mountain spur between the upper Indus and the Astor valleys and the Tangir and Darel valleys N of Sazin/Lower Indus.

The botanical fieldwork undertaken (1990/91) by G. and S. MIEHE revealed some 772 phytosociological

[1] The meteorologic stations include the following components: Data Logger by Campbell Scientific (CR10); Rotronic Temperature and RH Probe (MP100); Tipping Bucket Raingauge, 0.2 mm (ARG100 and DRG/3); Snow Depth Gauge (UDG01); Windvane (W200P); Anemometer (A100R); Pyranometer (LI200Z); Net Radiometer (Q-6); Thermistor Temperature Probe (107); Soil Moisture Block (227); energy supply by Solar Panel (SOP10); data are stored on a Solid State Storage Module (SM192). The mechanical stations include thermohygrographs of Lambrecht and Thies; rainfall is sampled by self-constructed totalisators with a collecting surface of 285.5 cm^2.

vegetation records after BRAUN-BLANQUET (as outlined in MUELLER-DOMBOIS a. ELLENBERG 1974), which are supported by more than 10 000 herbarium voucher specimens. These are being taxonomically and phytogeographically analyzed, together with all available earlier and later records (DICKORÉ 1995 and ms.). The preliminary vegetation survey presented here is merely based on plant formations which revealed to show characteristic climate-dependent variations in the study area. The nomenclature largely follows the UNESCO concept of a "tentative physiognomic-ecological classification of plant formations of the earth" (in MUELLER-DOMBOIS a. ELLENBERG 1974, 466), with some alterations and amendments. In contrast to most classification concepts used in the wider study area, the term "steppe" is restricted to plant formations dominated by graminoids, the term "meadow" is replaced by "alpine mat" and the term "desert" is merely used to designate (per-) arid landscapes which are devoid of any flowering plants in the zonal habitat.

3 Patterns of climatic humidity in the Karakorum and adjacent areas

WEIERS (1995) investigated the climate of the western Karakorum, especially the moisture patterns, using all available data suitable for statistical analyses (weather maps, satellite images, precipitation, snow accumulation and run-off). Accordingly, regional moisture gradients can be observed in the Karakorum as follows: summer (monsoon) moisture decreasing from SW to NE, and winter precipitation decreasing roughly from W to E. The resulting SW-NE gradient of decreasing annual precipitation is locally modified: high mountain ranges act as cloud barriers and cause a pronounced rainward/leeward differentiation of moisture, whereas broad longitudinal valleys (lower Indus, Gilgit and Hunza rivers) serve as pathways for the occasional intrusion of the southerly monsoon. The extreme dissection of the Karakorum, with a vertical relief usually exceeding 3000 m, causes a very steep, non-linear vertical gradient of moisture, with eu- or per-arid conditions on the valley floors and prevalent humid conditions in the sub-alpine/alpine belts. These features are illustrated in Figures 3 and 4, based on climatic measurements made in the course of the CAK project and published data from various sources (see figure captions).

WEIERS (1995) calculated the vertical increase of annual precipitation from all available rainfall, snow accumulation and run-off data and from the gradient measured in the Bagrot valley (CRAMER 1994), under consideration of varying topographical parameters. Two examples are shown in Figure 3. The altitudinal zone of maximum precipitation between 1800 and over 2000 mm/a is estimated to lie above 6000 m, where precipitation accumulates as snow and ice. In contrast, the annual precipitation in the montane and alpine belts is below 1000 mm, according to the present state of knowledge.

Examples of the climatic conditions in the Karakorum and adjacent areas have been compiled diagramatically in Figure 4 (Supplement IV.). The altitude of the stations increases from the bottom to the top (not to scale) and the aridity from left to right. The sequence types A to C occur in the W Karakorum, A and B being the subject of intensive research within the CAK project. For comparison, examples from the more arid adjacent mountain areas are given in columns D and E. The plant formations equivalent to these climate types are indicated using a physiognomic classification introduced in section 4.

The climatic diagrams after WALTER (1955), plotting precipitation and temperature in the ratio of 2 : 1, show the proportion between relatively humid (hatched) and relatively arid (dotted) periods of the year; the size of the dotted field indicates the severity and duration of the drought period. The lowest diagrams in each column (except B2 and C) and that of Skardu in the caption represent climates on the floors of the main valleys. All these stations have arid climates with a corresponding "sub-desertic" very open dwarf-shrub vegetation or even true desert (sequences C to E; desert climate diagrams only available from the per-arid sequence E: Kangxiwar in the Karakax valley (Xinjiang)).

The further the vertical distance from the valley floor, the stronger is the differentiation of the climate between constantly humid to per-arid conditions in the upper montane and alpine belts. Accordingly, the vegetation changes from closed forests/closed alpine Cyperaceae mats (column A) to montane and alpine deserts (E) in the driest areas towards the NE of the Karakorum. Thus the hygric classification terms chosen for the altitudinal sequence types A–E (analogous to ELLENBERG 1975, 1979; based on LAUER 1952) refer to the upper montane and alpine belts, where the differentiation of humidity and vegetation patterns becomes evident; it neglects the more or less uniform arid conditions in the valley floors. The fact that almost all long-running government climatic stations are located in the valleys, explains why the climate of the Karakorum has generally been described as arid, which leads to an underestimation of the potential extent of forested areas.

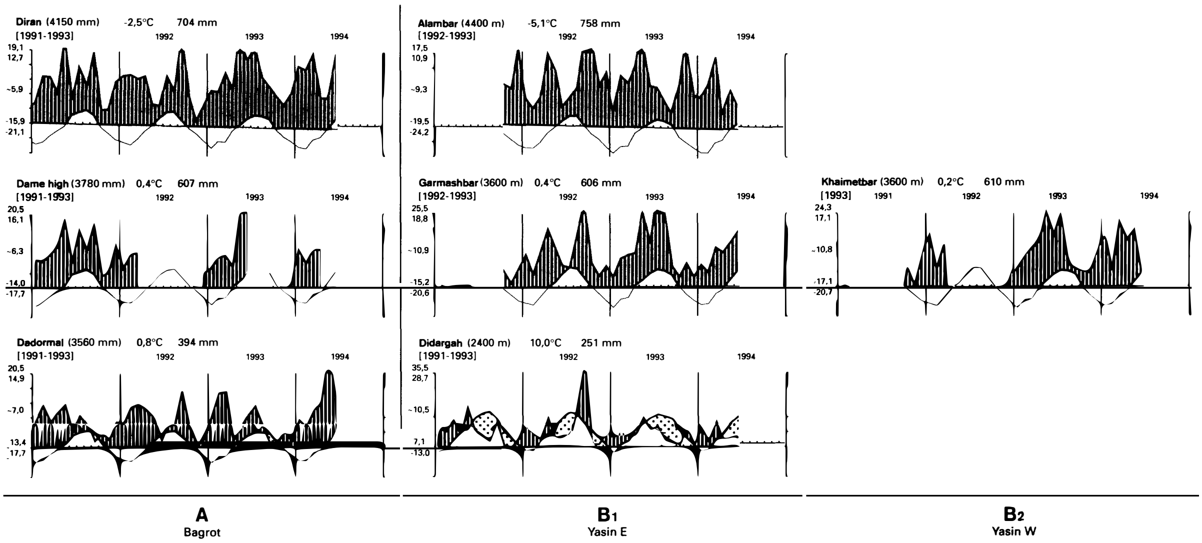


Fig. 5: Record series of precipitation and temperature at the longest-running climatic stations of the CAK project

Mehrjährige Niederschlags- und Temperaturdatenreihen ausgewählter Klimastationen des CAK-Projektes im Karakorum

Current climatic studies on selected mountain transects in two test areas of the CAK project area provide the first quantitative information on climatic altitudinal gradients. Data from the more humid areas in the W Karakorum have been collected by CRAMER (1994) in the Bagrot valley (Fig. 1). They are shown in column A of Figure 4 together with the long-running valley station at Gilgit and two examples from Naltar and Hunza; thus the series does not represent a uniform local gradient. Whereas Sat and Diran are part of a gradient on a S-facing flank in the still relatively monsoonal central Bagrot (corresponding to the vegetation pattern in Fig. 6b), the remaining Bagrot stations are located in the upper valley, moderately sheltered from summer monsoon precipitation (see vegetation pattern in Fig. 6a).

Semi-arid to sub-arid altitudinal belts are illustrated by the climatic diagrams from the Yasin valley system (JACOBSEN 1992, 1993, columns B_1 and B_2). Stations located in the main valley and its eastern tributaries (Fig. 2) have been compiled in column B1 even though the altitudinal changes are here cut across by those resulting from a horizontal, 50 km-long S-N-running gradient of decreasing monsoon influence (compare Darkot – Alambar at the head of the main valley with the remaining stations of the series). Two examples from the drier western tributaries are shown in column B_2 (note the increase of the summer drought in contrast with the B_1 stations at comparable altitudes!). The equivalent vegetation belts are outlined in Figure 8.

Comparison between the precipitation patterns from the Bagrot and Yasin should be carried out with caution: the diagrams are based on record periods of different length. Figure 5 shows the distribution of precipitation at those stations which provide the longest series. This compilation demonstrates the strong variability of both, precipitation totals and temporal distribution, from one year to the next. Longer record series are required before a reliable correlation between climate and vegetation can be attempted, and the variability itself is expected to be an important, at drought limits probably decisive factor.

Despite the short record series, basic regional differences in the spatial distribution of precipitation are indicated in Figures 4 and 5: Whereas the spring and summer (monsoon) precipitation dominates in the central W Karakorum (columns A), providing continuously humid climatic conditions during the growing period of the vegetation from c. 3600 m upwards, summer droughts may occur in the Yasin, where winter precipitation is more abundant. The obvious scarcity of precipitation during the warmest months might explain the more arid feature of the vegetation in Yasin, despite similar or even higher annual precipitation totals at comparable altitudes. The Yasin area, geographically and floristically transitional between Karakorum and Hindukush, is also characterized by its climate which is intermediate between the monsoon-influenced Indus/Gilgit valley system (column A) and the "Mediterranean" one of the Hindukush

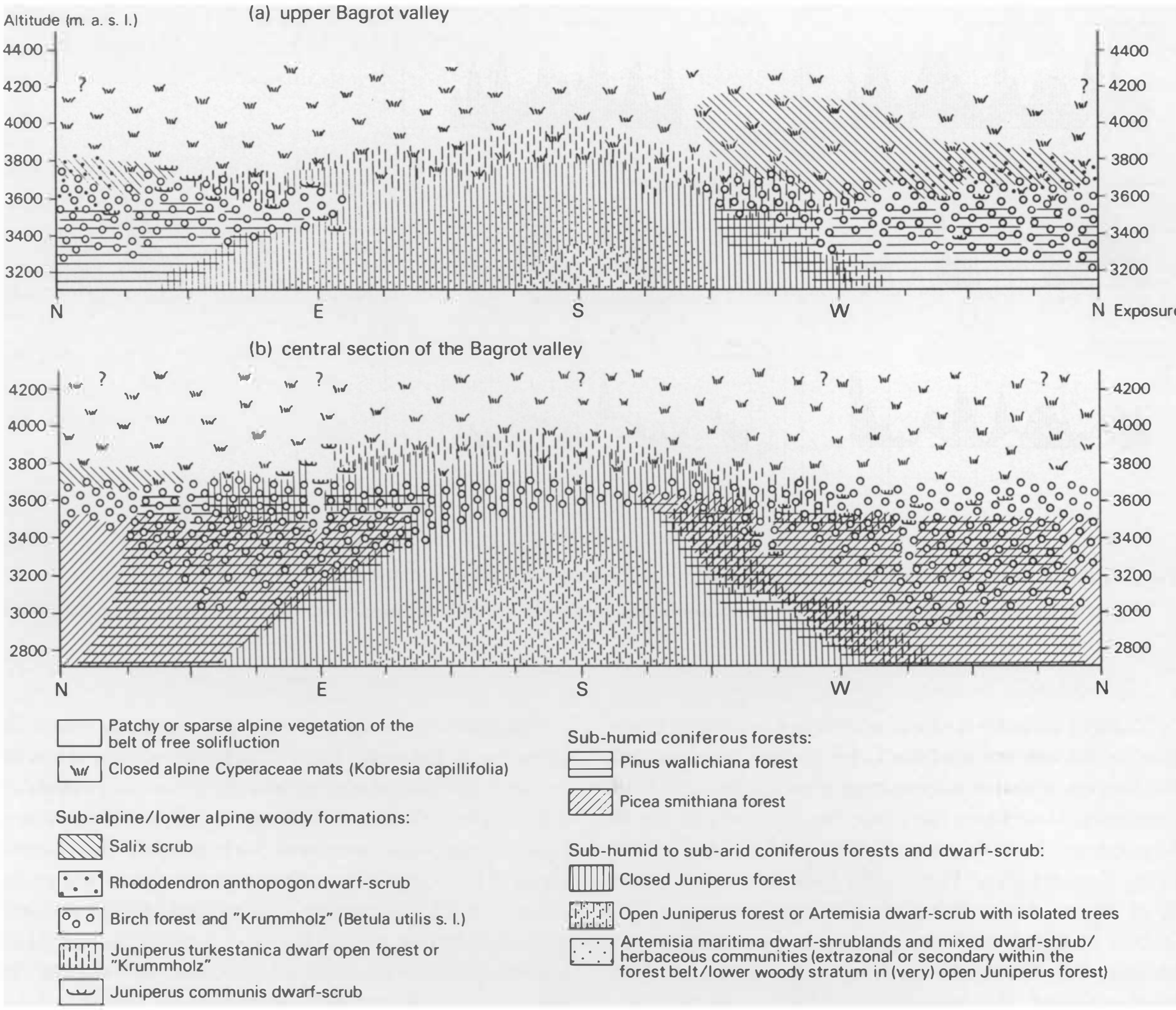


Fig. 6: Sub-humid sequence of altitudinal vegetation belts in the Karakorum: examples from Bagrot. Semi-schematic sketch of the zonal vegetation after field notes and records. Sketch method after BRAUN (1996), also Figs. 7–9

Vertikale und expositionsbedingte Verteilung subhumider Pflanzenformationen im Bagrot-Tal (Karakorum). Schematisierte Darstellung nach Verfahren BRAUN (1996), basierend auf Feldaufzeichnungen und Vegetationsaufnahmen. Vgl. auch Fig. 7–9

proper with its pronounced summer drought (see climatic diagrams in FREITAG 1971, 94). The Naltar station in series A (a western tributary of the lower Hunza) already shows a precipitation pattern similar to the Yasin type.

Also towards the eastern Karakorum, however, winter and spring precipitation seems to be more prominent than in the Gilgit/Bagrot area. This is suggested by the easternmost climate station of the study area (Skardu basin, valley base of an unknown semiarid sequence of altitudinal belts, see caption box of Fig. 4) and also by those located at the extreme southeastern margin of the wider Karakorum (Leh, column D; see also Kargil in HARTMANN 1983, 136).

Despite the limited statistical reliability of most climatic diagrams in Figure 4, due to the short measuring period, comparison of climatic and vegetation data allows a rough correlation of general moisture patterns with the main plant formations in the W Karakorum, described in section 5.

Oshikan-das (series A) represents the true "subdesertic" climate of the extremely xeromorphic Chenopodiaceae dwarf-shrublands in the colline/submontane/montane W Karakorum outside the local oasis-climates of permanent settlements. In the lower to upper montane belt, the majority of diagrams document the wide moisture range of the *Artemisia* dwarf-shrublands, in which *Juniperus* trees are dwarf and scattered or form open forests. The climate of the "*Artemisia* steppe", as this formation is frequently called, is arid near the drought limit of juniper trees (see Karimabad, series A, and Misgar, series C), but typically semi-arid, with precipitation totals between c. 200 and 400 mm.

The transition from open juniper forests to closed coniferous or birch forests takes place where the arid summer period disappears (Naltar, series A, Garmashbar, series B). Dadormal and Dame high (series A) represent sub-humid pine-birch forest resp. birch "Krummholz" climates, whereas the Garmashbar station is located in actually open but potentially closed *Juniperus* forest.

Diran (series A) gives a fine example of humid alpine climates with closed Cyperaceae mats, whereas Alambar (series B) illustrates the moisture conditions shortly above the upper limit of drier alpine formations (forb-rich steppe) with a more pronounced summer decrease of precipitation.

Data illustrating the arid to per-arid sequences of altitudinal belts are notably lacking from higher altitudes, so that the variety of sub-alpine/alpine formations indicated on Figure 4 between the closed mats in series A and alpine desert in series E cannot yet be correlated with the equivalent moisture patterns. The focus of the present study is, however, on the sub-humid to sub-arid sequences (series A and B) which are dominant in the W Karakorum.

4 General climate-dependent vegetation patterns in the Western Karakorum

In humid mountain areas, the temperature determines the most conspicuous formation change from the montane forest belt to alpine mats. Drought is (in combination with frost) a subordinate limiting factor. In semi-arid to arid mountains, however, lack of water becomes the primary limiting factor. Unfortunately both parameters enhance the adverse effect on plant growth in opposite altitudinal gradients: where the thermal conditions are optimal (in the valleys), the climate is driest (mostly too dry to support forests), whereas the highest general moisture is reached only far above the treeline. Thus there is a lower drought-caused limit of forests and a cold-effected upper one. In contrast with the latter, the altitudinal position of the lower forest limit varies markedly, depending on the local moisture conditions in any particular valley.

As illustrated in Figure 4, the lower montane valley floors are arid everywhere in the Karakorum. With annual precipitations between 100 and 150 mm, the local variation of the vegetation is limited: open dwarf-scrub composed of suffrutescent Chenopodiaceae dominates throughout; mostly, the vegetation covers less than 50% of the ground. Bunch grasses *(Aristida, Cymbopogon, Stipagrostis spp.)* are present in little grazed areas whereas annual Chenopodiaceae increase in magnitude in the vicinity of settlements. *Echinops cornigerus* and *Capparis spinosa* are locally conspicuous (alluvial fans and screes).

The upper limit of this arid dwarf-scrub is reached at c. 1900 m in the most humid areas and between 3100 and 3300 m in the drier parts of the W Karakorum. At these altitudes, the dwarf-scrub becomes more dense, the sub-desertic Chenopodiaceae species are replaced by *Krascheninnikovia ceratoides,* and wormwood gains importance (*Artemisia maritima* being dominant). Gramineae are prominent in these mixed dwarf-shrub/herbaceous formations *(Poa sterilis, Piptatherum gracile, Elymus cognatus)* if grazing is moderate. Scattered dwarf trees appear with *Artemisia* (*Fraxinus xanthoxyloides*, succeeded by *Juniperus excelsa* at higher altitudes).

This altitudinal sequence of lower montane plant formations is similar in all climatic sub-regions of the W Karakorum, except the eu-arid type described in section 5.4. It is in the central and upper montane belt where the effects of regional and local hygric differences are most pronounced: consequently the variability of the vegetation is highest there. To complicate the pattern, the local moisture conditions in a particular valley affect the vegetation to varying degrees in different slope exposures: the shady slopes have hygric advantages due to reduced insolation. The combined effect of these factors results in well-differentiated, moisture-dependent vegetation patterns which can be classified into four broad hygric sequence types of altitudinal belts. These are introduced in the following sections, and their distributions, as far as they could be mapped, are shown in Figure 9.

5 Moisture-dependent types of altitudinal vegetation belts in the Western Karakorum

5.1 The sub- to semi-humid sequence

This sequence of altitudinal vegetation zoning is encountered in the most humid parts of the study area (Fig. 9, see also Braun [1996] for examples from the Hunza Karakorum). The transition from arid Chenopodiaceae dwarf-shrublands to *Artemisia maritima* dwarf-scrub with scattered small trees takes place around 2000 m. Between 2300 and 2600 m, the vegetation on the sunny slopes starts to diverge from the one on the shady slopes. Two examples from the

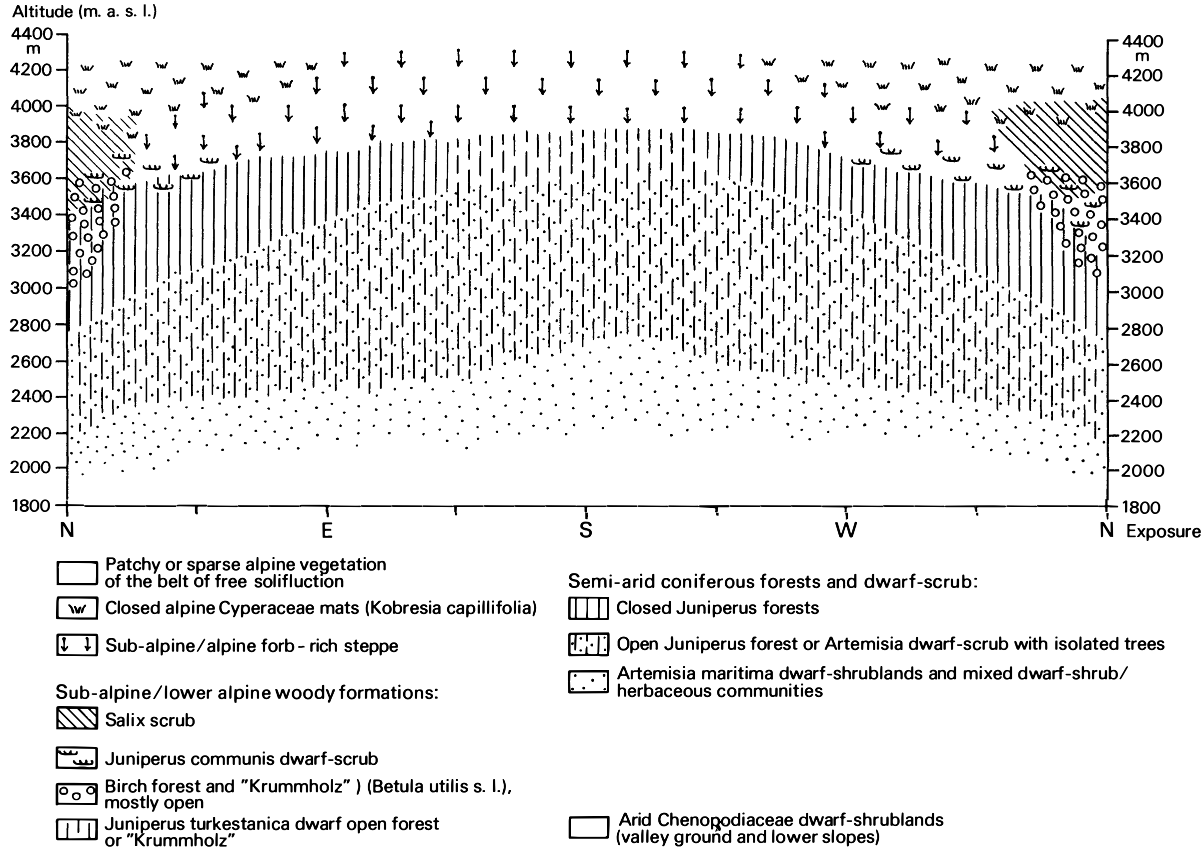


Fig. 7: Semi-arid sequence of altitudinal vegetation belts in the Karakorum: examples from Baltistan. Semi-schematic compilation after field notes and records

Vertikale und expositionsbedingte Verteilung semiarider Pflanzenformationen in Baltistan, basierend auf Feldaufzeichnungen und Vegetationsaufnahmen

Bagrot valley are given for illustration (Fig. 6); corresponding climatic diagrams are shown in column A of Figure 4.

On shady slopes (c. W to NE exposures), scattered *Juniperus excelsa* trees within the *Artemisia* dwarf-shrublands rapidly increase in density with altitude. Between 2300 and 2500 m, they start to form open and finally closed, 8 to 10 m tall forests. From c. 2700 m upwards, more moisture-demanding conifers replace the junipers (*Pinus wallichiana,* on more humid flanks also *Picea smithiana*) and constitute dense, up to 25 m tall sub-humid forests. In the most humid areas, firs *(Abies pindrow)* are sparsely present in northerly exposures (one locality known by the local people in the lower Bagrot, another occurrence was reported from Naltar (cited in PAFFEN et al. 1959), which is probably the northernmost outpost of this species). Further isolated records are mentioned by SCHICKHOFF (1995). Above c. 3200 m, birches *(Betula utilis* subsp. *jacquemontii)* become common understorey trees and form pure, up to 12 m tall stands above the upper limit of the conifers (c. 3500 m, see Dadormal station in Fig. 4). Towards the upper limit of birch forests (3700 m) the height of the populations is gradually reduced to 5–3 m low, snow-deformed open "Krummholz" formations in which *Salix* spp. and *Sorbus tianshanica* become prominent. In the small transition zone between the upper treeline and the alpine mats (Dame high station, Fig. 4), a scrub belt is well developed under undisturbed conditions: 0.5 to 2 m tall *Salix karelinii* thickets are most common. In the most humid areas, *Rhododendron anthopogon* dwarf-scrub represents the northernmost outliers of the Himalayan monsoon vegetation (seen in the Bagrot and in the Shinghai Gah mountains W of Gilgit).

On sun-exposed slopes, juniper populations within *Artemisia* dwarf-shrublands remain open up to at least 3000 m, even though they attain 8 to 10 m in height.

Relict populations indicate, however, that also in S exposure, closed juniper forests can occur above 3100–3200 m, where *Artemisia maritima* disappears in the undergrowth and Cyperaceae, *Ribes* and *Lonicera* spp. appear. These forests are constituted of two *Juniperus* species, the above-mentioned *J. excelsa* and *J. turkestanica* (DICKORÉ ms.). The latter species dominates near the treeline (3800–3900 m), where *Sorbus aucuparia* s.l. and in the most humid areas even *Betula utilis* appear. The "treeline" is in fact an artificial construction here, because *J. turkestanica* maintains its scapose life form but is gradually reduced in height until it attains a creeping "Krummholz" or dwarf-shrub habit (upper limit around 4000 m).

The alpine belt is characterized by closed Cyperaceae mats in all exposures. These are constituted of *Kobresia capillifolia,* which is accompanied by various moisture-demanding herbs, especially where the humus layer is injured by cryoturbation or grazing; e.g., *Bistorta affinis, Gentiana tianschanica, Pedicularis cheilanthifolia, Swertia petiolata* and the creeping chamaephyte *Salix flabellaris.*

The predominance of *Kobresia capillifolia* mats on all slopes separates this most humid sequence type from all the drier ones (see Diran station in Fig. 4). It can also be recognized in grazed areas, and thus, it is better suited for the assessment of the local hygric conditions than the forest belt where the indicative tree species have largely been removed.

The upper limit of the alpine belt is reached as low as between 4200 and 4300 m, where the mats disintegrate into patches and the sparse vegetation of the gelifluction belt takes over. In this zone, where the shortness of the growing season rather than the availability of moisture determines plant growth, the vegetation becomes again comparable in all humidity-dependent types of altitudinal belts introduced here (by analogy to the arid valley floors!). Typical life forms and species include cushion hemicryptophytes (*Androsace, Potentilla, Saxifraga* and *Sibbaldia* spp.), rosettes (*Saussurea* and *Waldheimia* spp.) and rhizome-hemicryptophytes (*Corydalis crassissima* and *Lagotis globosa,* both endemics of the Karakorum).

As far as is known at present, this most humid sequence of vegetation belts covers the largest part of the project area (Fig. 9): bordering on the outliers of the W Himalaya in the south (Nanga Parbat (vegetation first described by TROLL, 1939), Kaghan (SCHICKHOFF 1993) and Astor catchment areas), it reaches its northernmost point N of Chalt. The area roughly correlates with the occurrence of *Pinus wallichiana* in the respective slope aspect and forest belt (SCHICKHOFF 1995, Fig. 6). In the course of further phyto-ecological evaluation, this zone should be subdivided into a sub-humid one which flanks the lower Indus and Gilgit valleys and the lower Hunza valley W of Karimabad, and a semi-humid zone in the remaining areas which are more distant from the "monsoon pathway". The vegetation of the latter differs from the described sub-humid examples of the Bagrot in the following characteristics: *Picea smithiana* is absent from the N-slope forests, *Pinus wallichiana* may be reduced to a small zone in the uppermost *Betula*-dominated forests, and the closed juniper forests of the sun-exposed slope are confined to the uppermost sub-alpine zone (*Juniperus turkestanica* low forests and "Krummholz"). The *Kobresia* mats on the sun-exposed slopes of the alpine belt are affected by drought, becoming patchy and interspersed with species of the forb-rich steppes (see 5.2 and MIEHE 1995). With these characteristics, the semi-humid subzone forms the transition to the semi-arid sequence of altitudinal belts.

5.2 *The semi-arid sequence*

This sequence of altitudinal vegetation belts borders on the semi-humid one in all directions except the south and southwest (Fig. 9). It is illustrated in Figure 7, which compiles findings from Baltistan. The dry limit of this sequence type is shown by climatic diagrams from the more humid locations in Yasin (Fig. 4, column B_1), the only Baltistan example being from Skardu.

When the vegetation pattern in Figure 7 is compared with the sub-humid sequence in Figure 6, the much higher ascent of the *Artemisia maritima* dwarf-shrublands with *Juniperus* trees or very open forests is noticeable on all slopes. The exposure-dependent differentiation of the vegetation becomes merely conspicuous above c. 2800 m, where the juniper forests close on N-facing slopes: the lower limit of closed forests lies up to 500 m higher than in the sub-humid sequence, and the vertical extent of the forest belt is reduced from c. 1500 m to 800 m at most. *Picea smithiana* is absent, *Pinus wallichiana* is a rare companion in the birch forests above 3200 m, with little or no regeneration. *Betula utilis* forests are confined to strict N exposure; they are low and mostly open, allowing a well-developed undergrowth of *Salix karelinii* and *Juniperus communis.* The latter creeping dwarf-shrub is most conspicuous near the drought limit of birch forests and willow thickets (NE and W exposures) and generally in the westernmost parts of the Karakorum (Yasin, Ishkuman). Both scrub communities extend into the sub-alpine zone beyond the upper limit of *Betula utilis.*

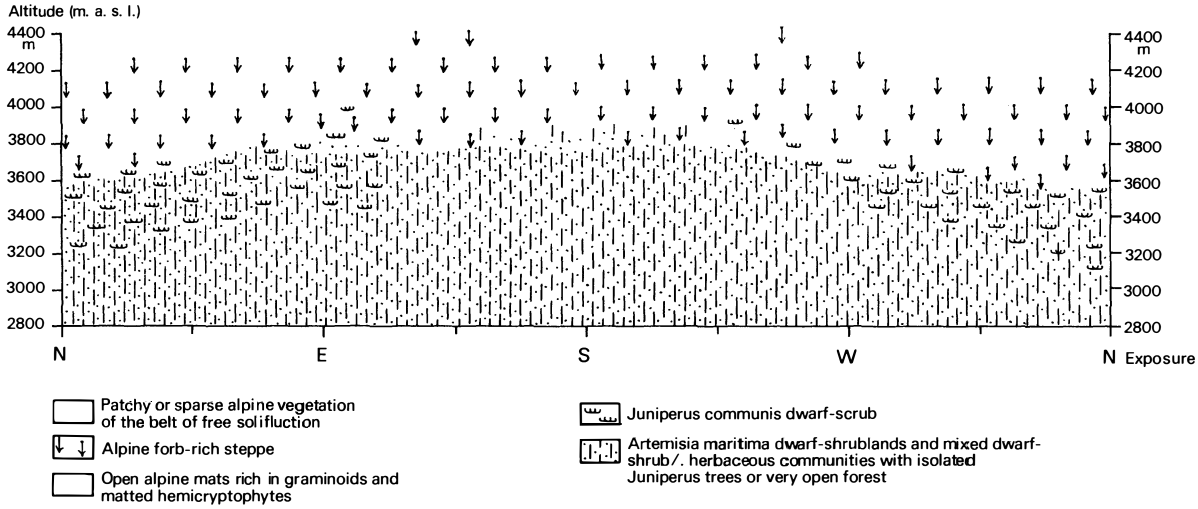


Fig. 8: Sub-arid sequence of altitudinal vegetation belts in the Karakorum: example Nazbar (Yasin). Semi-schematic sketch of the zonal vegetation after field notes and records

Vertikale und expositionsbedingte Verteilung subarider Pflanzenformationen im Yasin-Einzugsgebiet (Nazbar), basierend auf Feldaufzeichnungen und Vegetationsaufnahmen

On the sun-exposed slopes, the juniper forests also remain open above the upper limit of *Artemisia* dwarf-scrub, closing at most in the uppermost dwarf forest/ "Krummholz" zone (Garmashbar station, Fig. 4).

The alpine vegetation shows an exposure-dependent differentiation as well, in contrast with the sub- to semi-humid sequence type described above (Alambar station in Fig. 4 is located slightly above the alpine belt). Closed *Kobresia capillifolia* mats are confined to the shady slopes, whereas more or less open forb-rich steppes dominate the sun-exposed slopes. This formation is composed of tussock graminoids (Gramineae: *Elymus, Festuca* and *Poa* spp.; Cyperaceae: *Carex stenocarpa, Kobresia nitens* and *K. schoenoides*) and various hemicryptophytic forbs (typical are: *Potentilla gelida, Nepeta discolor, Oxytropis lapponica, Geranium pratense* s.l. and succulent Crassulaceae, *Rhodiola* spp. and *Sedum eversii*).

These semi-arid vegetation belts are widespread in the northern and eastern parts of the study area and probably cover areas as large as the sub- to semi-humid ones (Fig. 9). Owing to the more peripheral and scattered distribution and varying precipitation regimes, regional floristic differences are much more pronounced than in the previously described sequence type of the south-central W Karakorum.

5.3 The sub-arid sequence

Where the regional or local climate is even drier, closed forests are absent from zonal habitats: open plant formations grow in the montane and alpine belts at all exposures. The spatial arrangement of the respective communities is illustrated by the example of the Nazbar valley W of Yasin (Fig. 8); the montane climate is documented in column B_2 of Figure 4. As the valley floor of the Nazbar lies above 2600 m, the upper limit of the arid Chenopodiaceae scrub could not be shown. In the (more humid) main valley (Yasin), it ascends to 2300–2500 m. Above, *Artemisia maritima* dwarf-shrublands dominate the entire montane belt, ascending to c. 3800 m, where they pass into the alpine forb-rich steppes. Scattered *Juniperus* trees are mostly smaller than 5 m and form at most very open forests on shady slopes. The *Artemisia* shrublands are rich in aphyllous (*Ephedra* spp.) and thorny pulvinate dwarf-shrubs (*Acantholimon* spp.), which distinguish these dry *Artemisia* communities best from the wetter ones. Willows and birches grow only in water surplus habitats, along streams and flushes. On zonal shady slopes, the last persisting woody component of the birch forests is *Juniperus communis,* which forms mosaics with *Artemisia* scrub and causes the only marked floristic differentiation between the sun-exposed and shady slopes of this sequence type.

Within the alpine belt, exposure-dependent vegetation changes are inconspicuous and difficult to assess, in consequence of a strongly increased grazing pressure. Closed *Kobresia* mats are absent from zonal habitats. The forb-rich steppe of the shady slopes largely resembles the respective communities on sunny slopes in the semi-arid sequence of vegetation belts, whereas the communities of the sun-exposed slopes are transitional to the typical alpine steppes prevailing in more arid areas: the vegetation rarely covers more than 50% of the ground and is dominated by small bunch grasses *(Poa, Festuca)* and matted hemicryptophytes (*Oxytropis lapponica, Potentilla pamirica x sinonivea* complex).

Even though this type of altitudinal vegetation belts has been studied in only in a few places (Fig. 9), it is assumed that it covers large areas in the extreme NW Karakorum, extending northwards into the Wakhan (Pamir) and westwards into the Hindukush, but also in the drier parts of the central Karakorum, E and NE of the Baltistan locations visited. Comparable sequences (though floristically different) also occur in the eastern outliers of the Pamir and the western Kunlun Mts. of the adjacent Xinjiang Region (China).

5.4 The eu-arid sequence

This driest sequence type of vegetation belts is confined to the peripheral, extreme rainshadow areas of the study area (Fig. 9). Its complete mapping might help to specify the northern and eastern limits of the Karakorum proper as a climatic and floristic unit (for the latter see DICKORÉ 1995).

The only complete sequence of altitudinal belts studied was in the Shimshal valley, but the local variability of the climate in this large catchment area made a generalized compilation of vegetation units impossible. The only available climatic diagram (Fig. 4, column C) is from the slightly more rainy Misgar valley (N of Sost).

The sequence of vegetation belts differs from all those previously described by the absence of the montane *Artemisia* dwarf-scrub belt (in the dry extreme), and the almost complete lack of trees (*Juniperus turkestanica* relicts are mentioned by MIEHE 1995). In the valley floors of the lower montane zone, true deserts occur which are devoid of flowering plants. In the upper montane belt above 3000 m grow very open dwarf-shrublands, which are constituted of Chenopodiaceae; *Haloxylon thomsonii* dominates the lower and *Krascheninnikovia ceratoides* (companion in the *Artemisia* dwarf-scrub of the other sequence types) the upper zone, where *Stipa glareosa* is a characteristic companion. Only in the transition zone to the alpine belt (c. 4100 m on the sun-exposed slope) does the plant cover exceed 50 percent, and the number of species increases considerably: bunch grasses (*Elymus* and *Stipa* spp. and *Festuca olgae,* the latter forming a conspicuous belt as in the Kunlun and E Pamir), dwarf and prostrate shrubs *(Berberis ulicina, Dasiphora* spp., *Lonicera asperifolia* and *L. semenovii)* appear together with *Artemisia* spp. (not *Artemisia maritima!*) which are more common in the adjacent Kunlun than in the remaining areas of the W Karakorum.

The same applies to the constituents of the alpine steppe, where *Stipa purpurea* and the typical plate-shaped cushion plants appear *(Oxytropis ampullata, O. densa* and *O. pagobia).* Furthermore, *Artemisia minor* and *A. rupestris* are characteristic. On shady slopes, *Poa*-dominated grasslands may reach high cover degrees, giving the impression of closed alpine mats, but Cyperaceae are almost absent from zonal habitats. As a consequence of low precipitation and high solar radiation in this dry mountain area, the upper limit of the alpine belt ascends to 4700–4800 m.

This sequence of altitudinal vegetation belts is more similar to those reported from the north central and the eastern Karakorum (DICKORÉ 1991, K2; HARTMANN 1983, Ladakh; see climate of Leh in Fig. 4, column D), and from adjacent mountain massifs (e.g. the Issik valley/Wakhan described by HUSS 1978, the southern flanks of the western Kunlun studied by DICKORÉ 1991 and ZHENG 1988, "xerophilic pattern" with modifications). Related upper montane climates are shown from the E Pamir (Taxkorgan) and the extreme west of Tibet in column D of Figure 4.

The vegetation of this sequence type has few floristic and even fewer structural characteristics in common with the remaining one of the western Karakorum. The detailed phytosociological analysis of plant communities and the phytogeographical evaluation of plant records (DICKORÉ 1995 and ms.) will specify the degree of floristic relationship between the project area and the adjacent mountain ranges.

6 Conclusion

Evaluation of climate and vegetation data from sub-humid to sub-arid areas of the W Karakorum allows a preliminary correlation between the principal natural plant formations and the corresponding moisture patterns. The sub-humid sequence of altitudinal belts (example: Bagrot) is characterized by closed coniferous forests in the upper montane belt, which appear on shady slopes where the arid summer period is moderate and lasts less than 3 months; closed juniper forests appear on sun-exposed slopes c. 600–700 m higher up. Closed alpine Cyperaceae mats correlate with permanently humid conditions. The annual precipitation within this sequence ranges from c. 200 to c. 800 mm. Semi- to sub-arid sequences of altitudinal belts (climate examples gathered in Yasin) are climati-

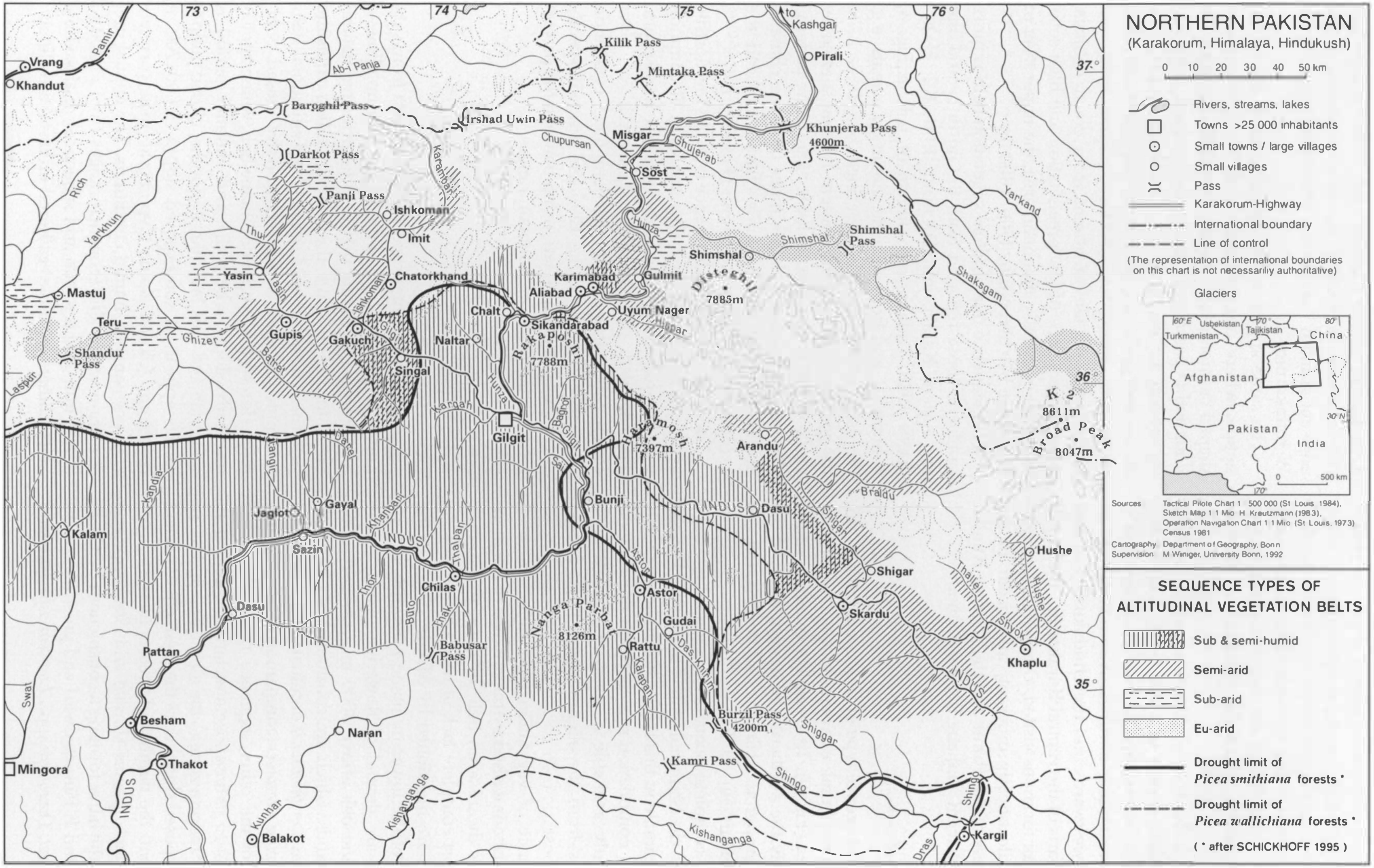


Fig. 9: Approximate distribution of humidity-dependent sequence types of montane and alpine plant formations in the western Karakorum. Preliminary sketch indicating the present state of knowledge. Sources included: see text (section 2.2). The Kaghan and Nanga Parbat areas S of the Indus belong floristically to the NW Himalayas

Angenähertes Verteilungsmuster feuchtigkeitsabhängiger hochmontaner und alpiner Pflanzenformationen im westlichen Karakorum. Vorläufige Darstellung des aktuellen Wissensstandes. Die südlich des Indus gelegenen Regionen des Kaghan-Tales und des Nanga Parbat sind floristisch dem NW-Himalaya zuzuordnen. Verwendete Quellen: siehe Text (Kap. 2.2) cally characterized by two to three months of summer drought which (due to lower temperatures) persists, slightly moderated, almost up to the alpine belt. Accordingly, open forests dominate, and alpine herbaceous communities close at most on shady slopes of the more humid areas. Annual precipitation totals only 600 to 700 mm in the alpine belt.

These two climate/vegetation zones cover the main areas of the western Karakorum. The most widespread montane plant formation is a more or less open *Artemisia maritima* dwarf-scrub with scattered to dense stands of juniper trees. The area of potential tree growth within this wormwood "steppe" has been underestimated in the past. It correlates with a variety of semi- and eu-arid montane climates with annual precipitation totals between c. 200 and 400 mm.

The driest climates of the W Karakorum have not yet been studied climatologically. The almost complete lack of trees and the sparse cover of plant formations from the valley floors (where true deserts occur) up to the belt of free solifluction suggest the persistence of pronounced arid periods of at least 5 months even in the alpine region. The only climatic diagrams of this eu-arid sequence are available from the SE Karakorum and the adjacent W-Tibetan areas, and from the eastern Pamir (Fig. 4). The per-arid sequence type of altitudinal belts, characterized by true deserts in the montane and alpine belts and constantly arid conditions, is absent at least from the W Karakorum.

Further data collection and evaluation within the CAK project aims to specify the correlation between climate and vegetation types and to increase the reliability of the climatic data. Based on the findings from the test areas, the extrapolation attempts concerning both climate and vegetation of the W Karakorum can be continued.

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Fig. 4: Compilation of available climatic data from the W Karakoram (A-C) and adjacent mountain areas (D-E), according to altitudinal gradients and degrees of aridity. The approximate correlation with altitudinal belts and broad physiognomic vegetation units is indicated.
Climatic diagrams according to WALTER (1955) drawn after data from various sources (see bottom of diagrams)

Zusammenstellung aller verfügbaren Temperatur- und Niederschlagsreihen des westlichen Karakorum (A-C) und benachbarter Gebirgsregionen (D-E), differenziert nach Höhenlage und Ariditätsgrad und verknüpft mit Vegetationshöhenstufen und -formationen.
Klimadiagramme nach WALTER (1955), Daten aus verschiedenen Quellen (unter den Diagrammen angegeben)