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DIFFERENCES IN EXPOSURE AND ALTITUDINAL LIMITS AS CLIMATIC INDICATORS IN A PROFILE FROM WESTERN HIMALAYA TO TIAN SHAN

With 12 figures (6, 7; 9–11 as supplements I–V) and 1 table

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Zusammenfassung: Expositionsunterschiede und Höhengrenzen als Klimaindikatoren in einem Profil vom Westhimalaya bis zum Tian Shan

Fünf Gebirgsabschnitte, die in einem Nord-Südprofil zwischen 43 °N und 34 °N in Teilgebieten Hochasiens liegen, wurden für eine numerische Ermittlung der Expositionsunterschiede der Vegetation sowie für die Festlegung von Höhengrenzen der periglazialen Oberflächenformung ausgewählt: das Turgen-Tal im Sailijskij Alatau (nördlicher Tian Shan), das Kuilju-Tal im Kuiljutau (Arpatakyr-Plateau zwischen südlichem und zentralem Tian Shan), das Oytagh-Tal am Kara-Bahtiyar (westlicher Kunlun), das Chaprot-Tal im westlichen Karakorum und das Kaghan-Tal auf der Südabdachung des Nordwest-Himalaya (Abb. 1). Diese Abfolge entspricht einem kontinental-ozeanischen Wandel mit sommerfeuchten Voraussetzungen im Norden und Zentrum bzw. winter- und sommerfeuchten Vorgaben im Süden. Die Untersuchungen erbringen folgende Erkenntnisse:

– In regionaler Hinsicht erweitert die Gegenüberstellung der Expositionsunterschiede und Höhenstufungen in den fünf Gebirgsabschnitten den Kenntnisstand vor allem im bislang weniger bekannten Oytagh-Tal und am Arpatakyr-Plateau (Abb. 9 und 10).

– Die überregionale floristische Verwandtschaft zwischen den Gebirgen ist eher gering. Die klarste Trennlinie befindet sich zwischen Karakorum und westlichem Kunlun, die den Tibet-Himalaya- vom Tian Shan-Komplex scheidet. Sie entspricht einer Grenze zwischen südlichen Gebirgen mit ausschließlich scharfen, glazial zugespitzten Gebirgskämmen und nördlichen Gebirgen, wo in Südlagen Schutt-Glatthänge eine periglaziale Überformung belegen.

– Es läßt sich in allen fünf Gebirgen eine ausgeprägte Stufe maximaler Expositionskontraste feststellen. Sie kennzeichnet den semiarid-semihumiden Übergang und befindet sich in den „trockenen" Gebirgen in mittleren (Abb. 7, 9, 10), in „feuchten" Gebirgen in niedrigen Höhen (Abb. 6 und 11).

– Aus angewandt-pflanzengeographischer Sicht erbringt die Methode der Ähnlichkeitsanalysen einen neuen Ansatz für die Klimainterpretation in semiarid-semihumiden Gebirgen.

– In klimaökologischer Hinsicht führen Überlegungen der Genese von Regionalströmungen mit den resultierenden Humiditätsmerkmalen zum Erklärungsansatz für das Fehlen bzw. Vorkommen bestimmter Höhenstufen, z. B. für jene der Dunkelwälder im westlichen Kunlun (Abb. 3).

– Die Gebirge mit den trockensten Fußstufen (Karakorum, Teile des westlichen Kunlun) zeichnen sich durch große Niederschlagsgradienten aus (Abb. 2). Die Angleichung der Humiditätsverhältnisse in den Hochlagen führt zu einer floristischen Annäherung zwischen den alpinen Stufen aller Gebirge (Abb. 12).

– Die Höhenstufung belegt zwar einen deutlichen Humiditätswandel vom ariden Profilzentrum mit hochliegenden Höhengrenzen sowohl bei der Vegetation als auch beim solifluidalen Formenschatz zu den humideren Eckpunkten mit jeweils absinkenden Höhengrenzen; jedoch können sich Teilbereiche der Gebirge im ariden Zentrum durch beträchtliche Klimaunterschiede mit entsprechenden Sprüngen der Grenzlinien auf kleinem Raum auszeichnen (Pfeile in Abb. 4 und 12).

Summary: Five mountain ranges were chosen for a numerical determination of exposure differences for vegetation as well as for the determination of altitudinal limits of periglacial land forms. A meridional transect crosses parts of High Asia between 43 and 34°N, including the Turgen Valley in the Sailijskij Alatau (Northern Tian Shan), Kuilju Valley in the Kuiljutau (Arpatakyr Plateau between Southern and Central Tian Shan), Oytagh Valley at Kara-Bahtiyar (Western Kunlun), Chaprot Valley in the Western Karakoram and Kaghan Valley located at the southern slopes of North-Western Himalaya. This sequence corresponds with the continental-oceanic change with summer precipitation in the north and central areas and winter and summer precipitation in the south. A brief summary of the results of this investigation follows:

The comparison of differences in exposure and altitudinal belts in the study area improves knowledge mainly in the less known Oytagh, Arpatakyr and Sailijskij Alatau. No major floristic relationship between the different mountain ranges was found. There is a distinct border between Karakoram and Western Kunlun that differentiates the Tibet-Himalaya complex from the Tian Shan complex. A distinct transmission of maximum exposure contrasts is present in all five mountain ranges. It shows the semi-arid transition, found in the medium altitudes of the "dry" mountains and in the lower altitudes of the "moist" mountains. The application of the similarity analysis is a new approach of plant geography to enable climatological interpretation in semi-arid to semi-humid mountains. The climatic-ecological view leads to estimations concerning the genesis of regional air streams and of humidity patterns. The latter can be used to explain the lack or presence of certain altitudinal belts, e.g. of dark forests in the western Kunlun. The Karakoram and parts of the Western Kunlun, the mountains with the driest foothills, are defined by a high precipitation gradient. The equalization of humidity in the high belts leads to a floristic similarity between the alpine belts of all mountain ranges. The altitudinal differentiation indicates a distinct change of humidity from the arid centre with its elevated position of vegetation-belts, as well as of solifluidal forms to the more humid borders with its depression of corresponding belts. However, some mountain areas in the arid centre show remarkable small-scaled differences in precipitation.

1 Introduction

The following analysis links up with former studies to develop methods of climatic indication using phytogeographical characteristics (RICHTER 1992). It is based on testing samples of vegetation structures that reflect regional climatic patterns and synergetic climatic features from areas where hygrothermic data is rare due to a poor grid of weather stations. Although the high complexity of mountain climates demands a very detailed climatic database, there is usually less statistical material from high mountains available than from lowlands. This deficiency reflects the growing need of climatic information in these ecologically and geomorphologically highly sensitive mountain areas where extreme hygrothermic events (e.g. droughts, rainstorms, extreme snowfall and frost events) lead to prompter and more intensive hazards compared to lowlands. These processes are reinforced as soon as human intervention takes place, especially in the subtropics and tropics where human migration advances on remote inner mountain areas. In these cases, invasion by man occurs mainly in areas where natural potential is largely unknown to the settlers. Therefore, agricultural colonization quite often results in inadequate types of land-use that are not adapted to given ecological conditions. Accordingly, sustainable cultivation must be based on ecological studies. In this respect, detailed climatic information is indispensable.

To a limited extent, concrete climatic information can be substituted by the interpretation of geomorphic landforms and vegetation. However, considering geomorphology, problems are caused by an overlying of paleoforms in the "ancient relief" (HÖLLERMANN 1976). The problem of the vegetational approach is produced by intermingling azonal with zonal sites or ecosystems altered by human impact. An alternative procedure for climatic interpretation in tropical mountains comprises the use of methods based on phytomorphological parameters of selected taxa or structural types. The latter system of indication seems to be hardly appropriate in mountains of the arid subtropical-tropical transition since basically xeromorphic structures are predominant. This is valid for desertic forelands influenced by drought and heat as well as for high altitudes with its extreme (UV-)radiation. Instead, considerations of life-form spectra and species numbers seem to be more appropriate, as shown in the example of the Merriam effect in the High Atacama of Northern Chile (RICHTER 1996).

"Phytoindication" (RICHTER 1997) must be considered as a keyword for the new method, documented here by using a statistical approach that analyses floristic similarity in different exposures as explained in *2.1* and described in *2.2*. A transect from western High Asia to Central Asia is presented as an area with a deficit of knowledge of processual climatic conditions. Proof of the value of this method is presented by the results of investigations in the Sierra Nevada and the White Mountains in California (HETZNER et al. 1997). Here a comparatively detailed database of climatic parameters correlates well with phytogeographical indices. These are based on taxonomic variations between different exposures.

In the case of the Asian mountains, two types and scales of exposures should be distinguished. SCHWEINFURTH (1984) points out that the entire Himalayan system displays its effect on the broadest scale, considering rain-shadow on north-facing and summer monsoon exposures on south-facing slopes. On the other hand, at a narrower scale the same author (1957), MIEHE (1984), TROLL (1939), WALTER a. BRECKLE (1994) as well as V. WISSMANN (1960) emphasize the fact that contrasts between vegetation of slopes exposed to the north and those exposed to the south become stronger by proceeding from the tropics towards the subtropics. Moist, dense coniferous forests, sometimes even with thick layers of mosses in shady stands, and steppes on sunny slopes are sharply divided from one another on crests. It is only this meso-type of exposure that will be regarded in this paper.

2 Objectives

The main issue of the investigation is the question how statistical analyses of similarity referring to vegetation on evenly placed plots can be applied to assess the conditions of humidity in mountains within an arid surrounding (humidity in this paper is always regarded as the annual mean of the amount of humid or arid months, respectively). This principle is based on the following simple reflections:

In an arid altitudinal belt, drought as the main ecofactor causes not only a limited diversity of species and life-forms, but also an assimilation of species' compositions on different exposed slopes due to poorer survival circumstances. Syntaxonomic conformity occurs as well in humid belts or mountains since equal moisture conditions stimulate the formation of a fairly homogeneous "optimal vegetation" based on the succeeding forces of the most competitive species. If these terms define a subalpine belt as spruce forests on both sides, floristic differences between north and south-facing slopes remain low since the canopy of the tree layer is determined by the humid macroclimate, whereas similar herb layers are determined by a uniform microclimate within the stands. Differences between the extreme exposures are limited to a mainly small vertical dislocation of the altitudinal belts dependent on thermic and radiation conditions (HETZNER et al. 1997).

However, semi-arid and semi-humid transition areas between arid forelands and humid high altitudes are inevitably determined by considerable exposure differences, due to the fact that evaporation rates are much higher on sunny slopes than on shady ones. In the first case, the water balance can lead to a deficit, while a surplus is present in the latter. The resulting analogy with the subalpine example would be an open tree steppe on the south slope and a dark coniferous forest on the north slope. In this vertical transition area, the similarity of species inventories and formations will decrease up to a turning point of a high syntaxonomic dissimilarity which results from maximum hygrothermic differences. From this turning point, conformity once more starts to increase with an increasing humidity. Theoretically, the turning point is equivalent to the transition-line between semi-arid and semi-humid conditions. However, comparable chemical and physical soil parameters are required for this principle and must be considered at the outset of the investigation.

3 Methods and investigation periods

Five sample areas were chosen for this investigation. Each location has a west-east running crest or valley that enables a comparison of quasi-natural vegetation plots on north- and south facing slopes (in this context, "quasi-natural" is defined as follows: disturbances by man should be as low as possible. A totally undisturbed area cannot be found in those regions since grazing influences have been present, mostly for centuries). The three authors stayed in each sample area for approximately seven days to carry out vegetation relevés in seven to nine altitudinal levels each on the north as well as on the south slopes at vertical intervals of 250 m. The percentage coverage, as well as the number of species, were recorded on five sample plots of 1 × 10 m placed in a strip transect on each level to receive an objective data-set regarding the comparison of both exposures. It must be emphasized that this approach, based on 5 × 78 = 390 relevés in five different valleys, is restricted to the method of a rapid and efficient climatical phytoindication; it does not follow usual processes for characterizing syntaxonomical differentiations at all.

In each sample area the relevant plants for each belt were collected (approximately 400 species altogether; in this context, "relevant" is defined as "frequent" or "steady"). The determination of the occurring species was carried out for the Kaghan-, Chaprot- and Oytagh Valley by Dr. W. B. DICKORÉ in Göttingen, for the Arpatakyr by Dr. M. DANILO and for the Turgen Valley by L. STOGOVA (Inst. of Botany, Acad. Rep. Kazakstan, Almaty). Undetermined species were integrated with a provisional name in the statistical similarity analysis based on JACCARD's formula[1] and the dendrogram calculations using the MULVA program. Each species was already provisionally related to one specific life-form during field work on site.

Calculations for the similarity analyses were carried out with regard to the following objectives (the analyses were plotted separately in Figs. 6–7 and 9–11, Suppl. I–V):

- Comparisons in scatter diagrams between the JACCARD-values of the non-weighted relevés and those of the weighted relevés by reference to the coverage determine the degree of exposure differences (bottom left in each Fig.).
- Dendrograms illustrate the information about the separation of plant communities on a numerical base (bottom right). From the various transformed calculations, only those are presented that agree with our subjective conception of a community classification.
- Comparative life-form spectra allow qualitative profile differentiations. They indicate whether altitudinal belts are present with or without specific exposure differences (in this context, "specific" means "syntaxonomically independent").

These detailed phytogeographic investigations, carried out in five regions (Fig. 1), are included into further analyses that will deliver the frame for the entire profile. These analyses contain the following methods:

- The record of cryogenic landforms and their vertical extent in eight additional mountain areas between

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[1] SI = (C / A+B–C) 100; with SI = similarity index; C = species occuring in both and A, B species occurring only in one of two plots.

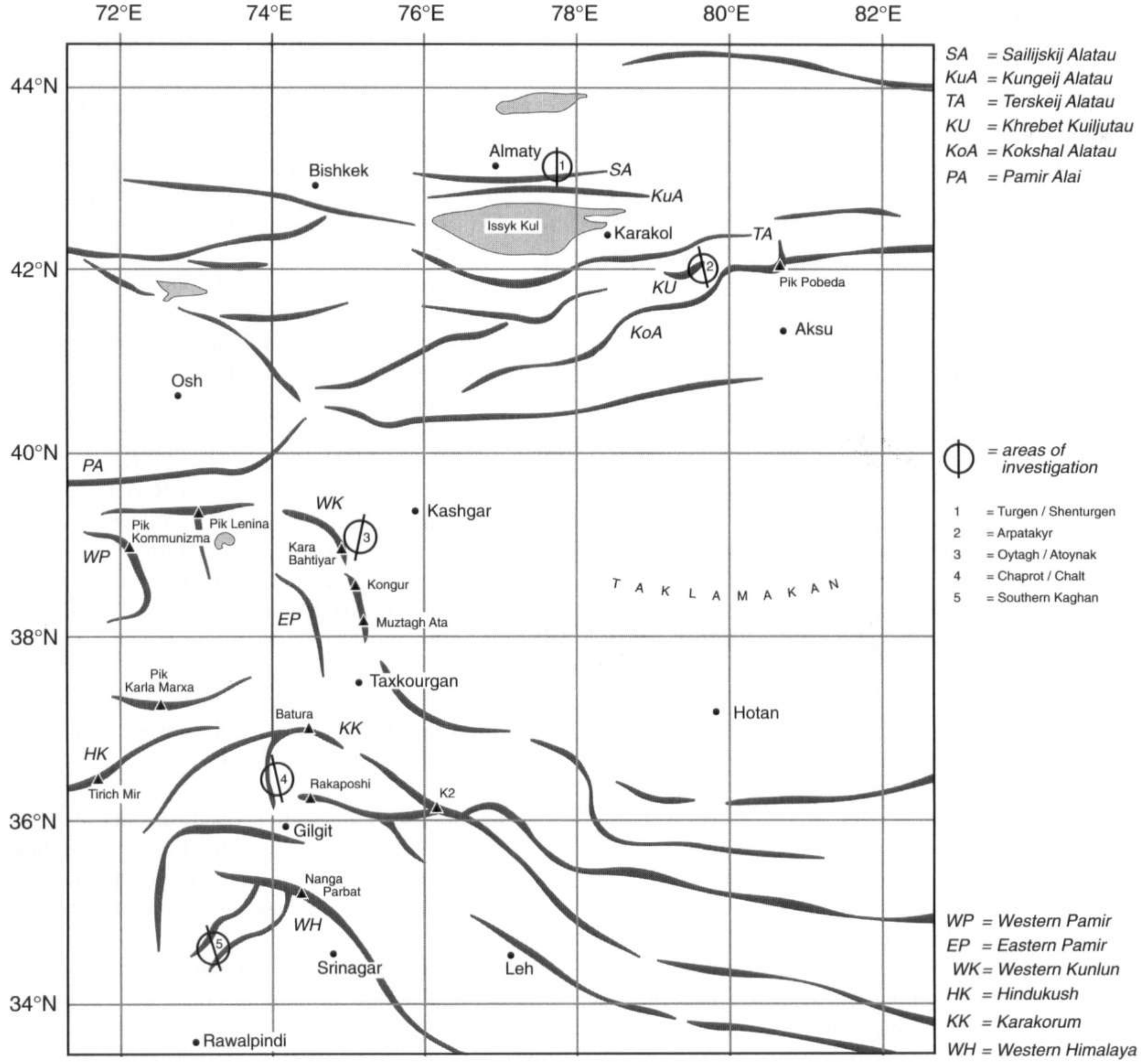

Fig. 1: Location of the five study areas
Lage der fünf Untersuchungsgebiete

the Western Himalaya and Northern Tian Shan (Fickert 1998) support and complete the results of phytoindication regarding the amount of humidity.

– Climatic data of the surroundings of the five regions are collected and transformed into calculations of lapse rates and related to altitudinal borderlines (periglacial belts, treeline etc. in Fig. 2).

– Personal weather observations in Oytagh and Arpatakyr help to characterize these mostly unknown areas synoptically. These conceptions, shown in Fig. 3, are based on poor representative data of only one week in each area. On the other hand, these observations, based on a consistent weather-situation and correlating with phytogeographic patterns of distribution, provide an initial indication for further research. Although the observations only refer to summer conditions, they represent a major factor for ecoclimatic vegetation structures.

Since only vegetation records from summer months are useful, the first stay in northern Pakistan, western China and southern Kazakstan was in June/July 1996, the second one in July/August 1997 in northern Pakistan, Kirgistan and northern Tadjikistan. A total of seven valleys was visited using public transportation for getting access, whereas the areas themselves were investigated by hiking. Five of these regions turned out to be appropriate for the studies. During the first stay the researchers carried out field work for one week in each area: Chaprot Valley in Western Hunza-Karakoram, Oytagh Valley in Western Kunlun and Turgen Valley in the Sailijskij Alatau. In 1997, the investigations were continued in Kaghan Valley (Western Himalaya) and Arpatakyr Plateau (Kuiljutau) for one week each (Fig. 1), additionally for four days each in Tasry Koy Valley in the Fergana Range and the upper Jagnob Valley (Pamir Alai).

4 Climatological observations

Referring to the weather station of Balakot, the lower Kaghan Valley is the only exception of the five study areas to be located in a humid area (Fig. 2 and SCHICKHOFF 1993). Secondary frontal westerly disturbances in late winter and early spring, as well as summer monsoons, are the major factors influencing this situation (WEIERS 1995). Frontal events are responsible for relatively high humidity in the northern Tian Shan, too. Here, a superposition of a northern branch of the jet stream results from divergent air flow into this section from the barrier in the west of the Central Asian Highland (BÖHNER 1996). The three remaining mountain ranges investigated rise from desert regions in a leeside position.

For each mountain range, correlations of hygric and thermic gradients are based on data-sets of the weather stations within and around the study area. The results shown in Figure 2 are derived from compilations in FRANZ (1966), LYDOLPH (1977), MIEHE et al. (1996), REIMERS (1992) and SCHICKHOFF (1993) as well as from statistical compendia of the former Soviet Republics (SPRAVOTSCHNIK PO KLIMATU SSSR 1966 a. 1969).

The comparison presents values between 0.5 and 0.6 K/100 m for the thermic altitudinal gradients except for the Tian Shan. There, in the area of the Syrte, a remarkably low gradient in January indicates layers of cold air masses at the lower stations. Inversions at higher altitudes of the Sailijskij Alatau result in vertical temperature deviations (SEVERSKIJ, I. W. a. SEVERSKIJ, E. W. 1990). Furthermore, according to the latitude, temperatures are lower in the two Tian Shan mountain ranges at all levels than in the three southern mountain areas. – Precipitation conditions show even greater variations. It should be pointed out that the altitudinal change in the Eastern Pamir presented here does not refer to the special situation given in the moist glacial valley of Oytagh in Western Kunlun (see below), but to the dry plateau between the two mountain ranges.

Later on, a concluding analysis of the humidity conditions will lead to an explanation of the very complex climatic differentiation within single mountain sections. In this sense, HEWITT (1989) emphasized the rapid change of altitudinal limits and of particular zones within the Karakoram range in meridional as well as in longitudinal direction. PAFFEN et al. (1956) gave much attention to the broad regional gradients of moisture supply, temperature and vegetation cover in the Central Karakoram. Furthermore, the great importance of local climatic variations of the overall Himalayan system, including its adjacent eastern and western surroundings was described by FLOHN (1969), SCHWEINFURTH (1984), TROLL (1947), and V. WISSMANN (1960/61). In this context, the gradient analysis in Figure 2 only reflects a rough orientation of the real conditions. On the other hand, it suggests a first climatic overview from the southern to the northern high mountains, i.e. High Asia including Central Asia.

Within this profile the records of the very short weather observations in Oytagh from 30.6.–6.7.96 and in Arpatakyr from 22.7.–29.7.97 as well as further observations in Gez Valley and at Issyk Kul lead to preliminary reflections about air-flows in the lower troposphere as illustrated in Figure 3 (centre). In this context, the descriptions by MURSAJEW (1966) that point out the importance of north-eastern winds from the western basin of Tarim and their positive effect of summer rains on the vegetation of the "mountains southwest of Kaschgar" are useful. So, our model assumes convergent streamlines running into a shallow heat depression in central Taklamakan according to a sketch by YANG (1991) for the summer months. Here, the daily flow of air masses in breached gorges like the Gez Valley and Taxkourgan River Valley in Western Kunlun can be interpreted as a shallow air stream up to secondary turbulent centres above the plateaus around Bulunkul and Taxkourgan. These stormy valley winds are likely to be divergent deviations from the convergent main stream direction into the desert centre. Heat effects on the plateaus provide the major impulses (equivalent descriptions by HAFFNER 1997, RICHTER a. LAUER 1987, SCHWEINFURTH 1956, TROLL 1952, V. WISSMANN 1960) for updraughts in the gorges in the daytime. These local fluxes are overlaid by westerly streams indicated by frequent clouds of blowing-snow at the top of Kongur and Kara-Bahtiyar.

While the stormy thermally-induced upwinds in the Gez Valley, manifested by dune accumulations around Bulunkul at the eastern slopes of Eastern Pamir (Sarykol), result in drought effects, in the case of Oytagh winds in a glacial valley show a contrary impact (Fig. 3, bottom): above the ice lobes at an alti-

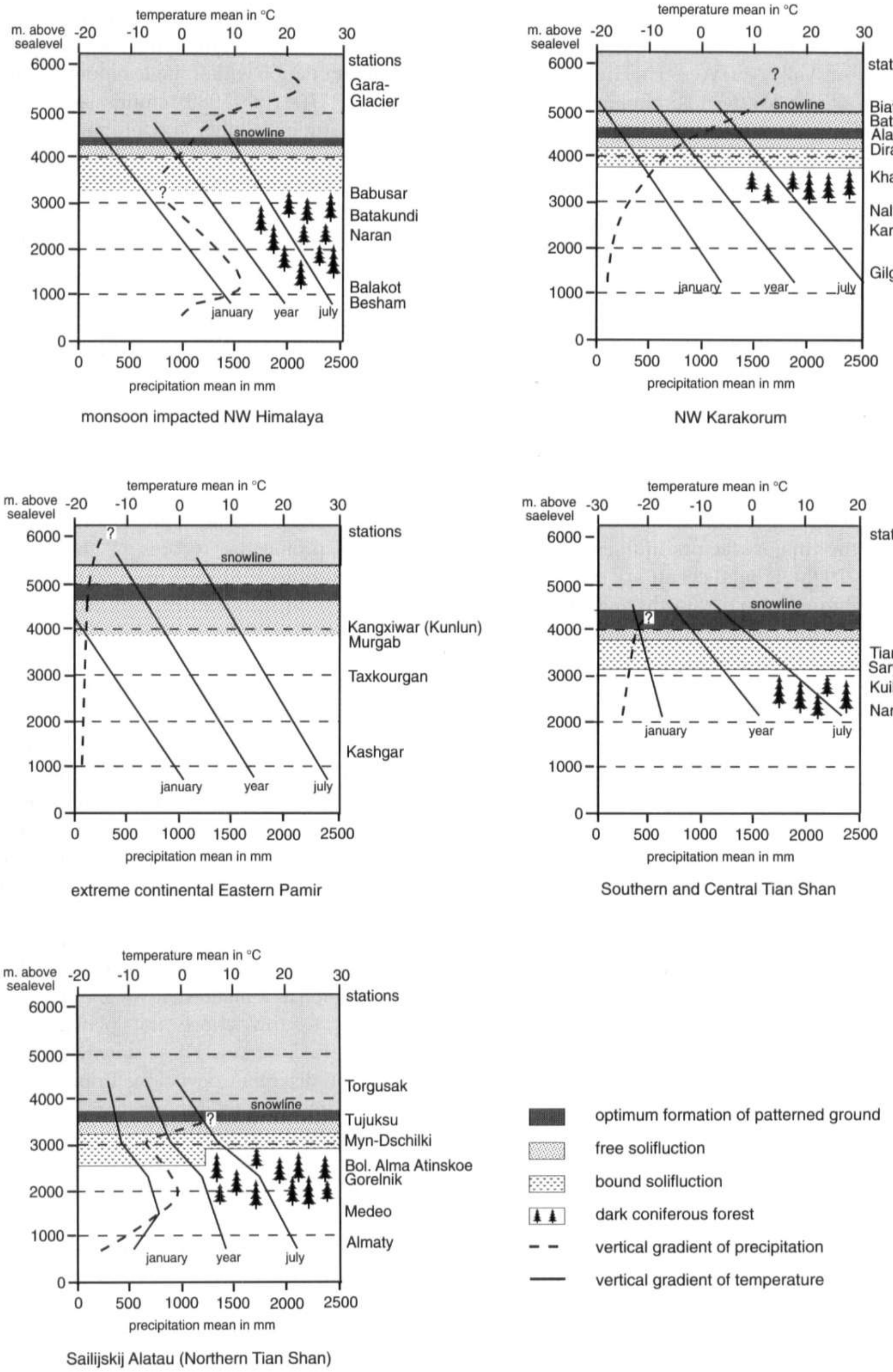

Fig. 2: Vertical gradients of temperature and precipitation with regard to altitudinal borderlines in various mountain ranges of western High Asia

Vertikale Temperatur- und Niederschlagsgradienten in bezug zu Höhengrenzen in verschiedenen Teilgebirgen im westlichen Hochasien tude of 2700 m above sea level, a turbulent vortex is caused by relative moist katabatic glacial winds and dry, dust-carrying upwinds from the desert foreland. Clouds form frequently in the afternoons due to condensation provided by dust particles in the convective cells. During the field work period, short but severe rainfall occurred every day, explaining the residual hydrophilous dark coniferous forests at an altitude of 3000 m and around the glacier lobe. These rainfall events are rare at lower elevations where precipitation evaporates before it reaches the surface (typical features: a few large rain drops falling down and precipitation strips some 100 m above the valley bottom).

At the southern and south eastern slopes of the Pik Pobeda in the Kokshal Alatau, the same system is likely to be effective. The control of stream deviation passing the Aksay Valley probably proceeds from the Western Syrte around Torugart. However, these descriptions of process must still be considered as a hypothetical approach, since the authors could not stay in the restricted border area with Kirgistan (Fig. 3, centre). Nevertheless, some facts point to this phenomenon:

From Arpatakyr, for example, high elevated cloud formations in summertime can be observed above the southern and south eastern Pobeda Massif, that are already formed in the late morning and result in sheet lightning from late afternoon until evening in their dark bottom area (Fig. 3, top). Referring to the Soviet topographic maps 1:200 000 (four sheets including the complete coverage of the Chinese escarpment), the southern escarpment especially is defined by numerous valley glaciers covered by spruce forests in their vicinity. As soon as this effect of mass-elevation is diminished, as in the western part of Kokshal Alatau, and particularly at the breach of the Aksay Valley towards the plateau of the Western Syrte, such forests seem to be absent. Towering cloud formations as observed around the Pobeda Massif are less obvious here. In the map of streamlines (Fig. 3, centre) the glaciated valleys proved as humid with probable convective precipitation genesis are marked by a circle, whereas strongly ascending winds are marked by an arrow.

Another remarkable phenomenon is the summerly foehn in the area of the Eastern Syrten Highlands between Terskeij and Kokshal Alatau illustrated in Figure 3 (top). It does not start before early afternoon and is dependent on ascending moist air masses from Issyk Kul on the windward side at the northern slope of Terskeij Alatau (but not necessarily on rainfall). Referring to BARRY (1992), these are possibly cyclonic foehns in a stable troposphere, receiving an additional impulse by relative constant low-level westerlies (derived from Fig. 6.22 in BARRY a. CHORLEY 1987). This jet, as well as the dry foehn winds at the northwestern side of Pik Pobeda, may contribute to turbulences with the local katabatic glacier winds promoting a convergent updraught as a trigger for the late afternoon thunderstorms. The remarkable cumulonimbus above the massif does not start disintegrating before the foehn ceases at around 8 p.m.

On the other hand, the drought-causing input of relatively warm air streams in the eastern Syrte with fall winds reaching down into the deep gorges of the Sarydschaz and Inylchek cause an open, xerophilous vegetation with *Artemisia brevifolia* and *Stipa capillata* as characteristic species at the southern exposures between 2500 and 3000 m. Under the given circumstances the *Picea schrenkiana* forests with interspersed *Salix spp.* on the northern exposures, seem to be misplaced. It is however noticeable that spruce needles are smaller and substantially brighter here than on the nearby northern slopes of the Terskeij Alatau or further south in the Oytagh.

5 Geomorphological aspects

As a first reference to climatic vertical characterization of the profile from Western Himalaya to Northern Tian Shan, results concerning the altitudinal distribution of solifluidal forms precede the phytogeographical interpretations. Figure 4 indicates an expected rise of the geomorphologic belts in a peripheral-central sense. According to TROLL (1947) this phenomenon does not proceed in a strictly parallel form. Rather than that, the upper tree-line caused by thermal conditions shows a less pronounced rise compared with the snowline caused by hygric reasons (HÖLLERMANN 1985). The belt of solifluction thereby experiences a vertical extension with increasing continentality (HÖLLERMANN a. POSER 1977); as in the dry central part above the Taklamakan, free solifluction predominates over the bounded one. IVANOV's world map describes this region as already belonging to the high-continental Eurasiatic centre (LYDOLPH 1977).

The fact that within the profile substantial gaps occur, which cause a regional contraction of the solifluction belt, is noteworthy and most likely new in this dimension. This mainly concerns the Western Kunlun, where "humid" glaciated valleys show a depression of the snow belt and therefore also lowers the upper limit of patterned grounds up to 500 m in relation to the adjacent "arid" breached valleys. Here, even the spruce forests that occur in the profile at the Kara-Bahtiyar are missing. In the Tian Shan all altitude belts descend in the direction towards the Kazakstan lowlands. This

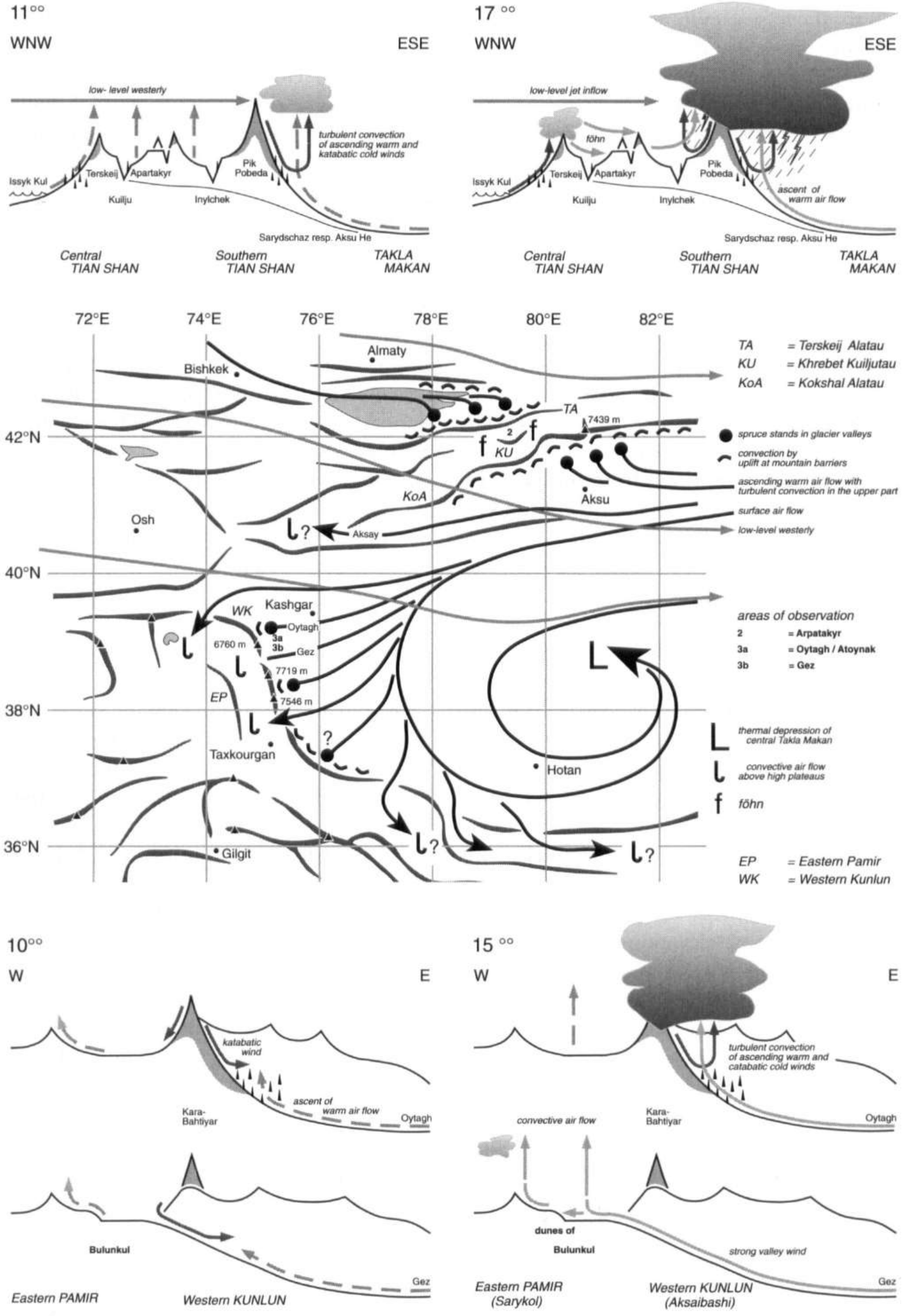

Fig. 3: Hypothetical reflections on the genesis of dry valley winds and "moist" updraughts in convective cells in the Kunlun and Kokshal Alatau as well as of foehn effects in the Syrte. The upper profile shows the positions of air streams and air-blocking in the Central to Southern Tian Shan, while the lower profile series illustrate appropriate features between Western Kunlun and Eastern Pamir

Hypothetische Überlegungen zur Genese von trockenen Durchbruchströmen und „feuchten" Aufwinden im Kunlun und Kokshal Alatau sowie zur Föhnwirkung in den Syrten. Über der Aufsicht in der Mitte zeigt ein Profil die Strömungs- und Staulagen im zentralen bis südlichen Tian Shan, während die unteren Profilreihen entsprechende Merkmale zwischen dem westlichen Kunlun und östlichen Pamir vorstellen

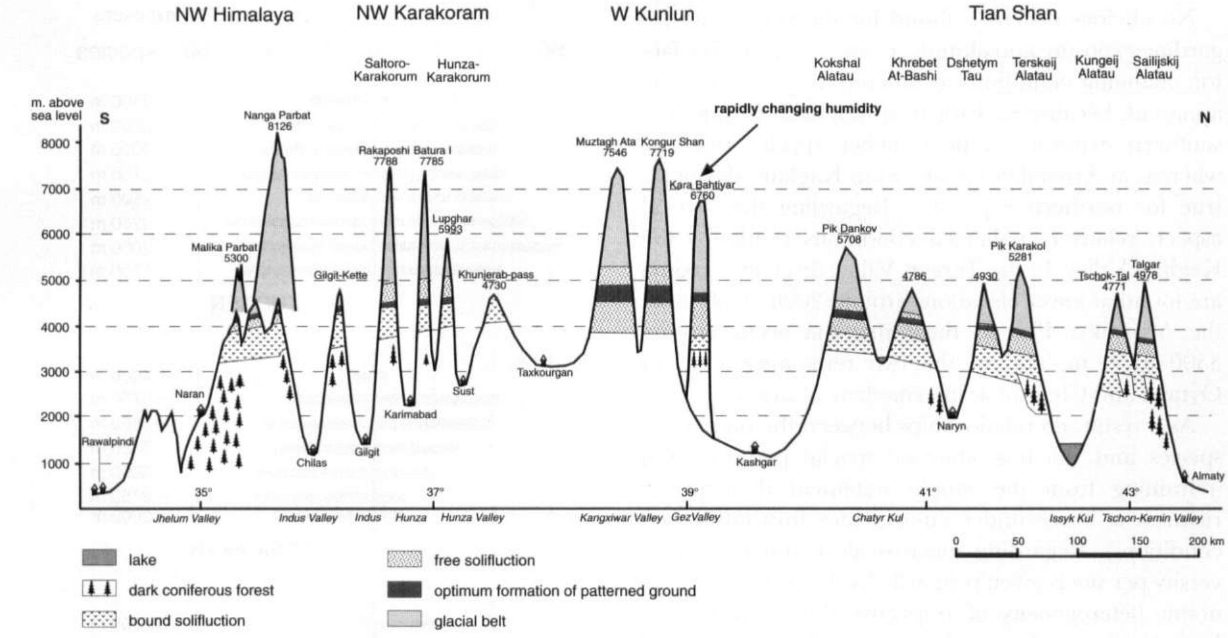

Fig. 4: Some geomorphologic and phytogeographical belts in the western part of High Asia
Einige geomorphologische und pflanzengeographische Höhengrenzen im Westteil Hochasiens

trend does not only follow the gradients of continentality but the polar reduction of the warm season, too. A detailed study of the distribution of periglacial forms in Central Asia was recently published by FICKERT (1998).

6 *Phytogeographical investigations*

The Western Kunlun and Eastern Pamir do not only form the vertex of solifluction and forest belts, but probably an important dividing line within the Irano-Turanic Floristic Region as well. Thus, due to its taxonomic mediterranean relationship the Western Himalaya might be assigned to the Western Asiatic subregion, while the monsoonal influences explain Sino-Japanese elements of the Eastern Asiatic region (SCHICKHOFF 1993; DICKORÉ 1995). This transitional zone in the sense of TAKHTAJAN (1986) becomes separated from the Central Asiatic subregion; here, the same author regards the boundary between the Central Tian Shan Province and the Tibetan Province following south as still unclear. The floristic spatial pattern of *Picea schrenkiana* belongs to the first, which is found in the Oytagh, too. Further species support the idea that the humid glaciated valleys on the NE slopes of the Kunlun already belong to the Central Tian Shan Province, while the plateaus between Kunlun and Eastern Pamir belong to the Tibetan Province. A separation of a specific Eastern Pamir Province, as detached by MEUSEL et al. (1965), does not seem very plausible.

In a compilation the study areas can be assigned to the following floristic provinces:

Kaghan	to the Western Himalayan Province
Chaprot	to the Tibetan Province
Oytagh and Arpatakyr	to the Central Tian Shan Province
Turgen	to the Dschungaro-Tian Shan Province.

According to our own relevés (Fig. 5), the suppositions for the diversity of species per site in the five study areas are different. If the species richness in each sample area per elevation level is used as a database for α-diversity (here number of species per 50 m^2), then maximum values in the optimum belts range from 32 species in the Kaghan Valley (northern exposure at 2250 and 2500 m) to 63 species in the Turgen Valley (southern exposure at 2000 m). Regarding all investigated levels, the two mountain sections in the Tian Shan indicate the highest means (41 species/50 m^2 in the Sailijskij Alatau and 28 species/50 m^2 in the Kuiljutau). Oytagh and Chaprot, the driest sections with eu-arid and sub-arid foreland show the lowest amounts (23 and 23.5 species/50 m^2), while the humid lower Kaghan Valley indicates medium values of 26.5 species/50 m^2.

No obvious system is found for the α-diversity regarding exposure and altitude. Concerning the first factor, changing conditions at different altitudes become apparent, because in Turgen as well as in Oytagh the southern exposures reflect higher species richness, whereas at Arpatakyr (as well as in Kaghan) this holds true for northern exposures. Regarding the vertical aspect, relatively balanced conditions result for the Kaghan Valley. In the Turgen Valley diversity maxima are found at lower elevations around 2000–2250 m; at the Arpatakyr Plateau these maxima occur around 3500–3750 m, and in the two remaining areas of Oytagh and Chaprot at intermediate altitudes.

As a result, no relationships between the number of species and the hygrothermic spacial patterns exist (refraining from the simple statement that species richness is lower under eu-arid and frost-influenced conditions). Regarding macro-scale conditions, α-diversity per site is given primarily by the degree of taxonomic heterogeneity of respective floristic provinces. From this point of view, the montane to alpine belts of Tian Shan, Alai and Pamir are characterized by a high diversity (4700 species in total, Agachanjanc 1980).

In the study areas with their varying floristic features, the focus of the investigations derives from several phytogeographical statistical calculations, the results of which arranged as follows (Fig. 6–7 and 9–11, Suppl. I–V):

– top: profile sketch with denomination of communities; their segregation follows the numerical classification described below. The nomenclature follows the principles of "community ecology " (e.g. Whittaker 1975), that designates a community according to constant species assigned to a formation type

– centre: life form spectra representing mean values of all five levels per belt; hemicryptophytes are differentiated in grasses and herbaceous perennials

– bottom: similarity analyses after Jaccard in an unrevalorized form (open circles) as well as revalorized by percentage coverage (full circles) in the coordinate system left.

– right: dendrogram based on classifications by the "procedure of minimum variance" (Glavac 1996) with similarity calculations, to get an objective separation of the units designated in the profile (given by the dividing line in the cluster).

The individual investigation areas are regarded separately in the following chapters.

6.1 Kaghan/Western Himalaya (34°40' N, 73°25' E; Fig. 6, Suppl. I)

Unlike the four subsequent cases, the crossing of a mountain crest was not possible in the Kaghan Valley,

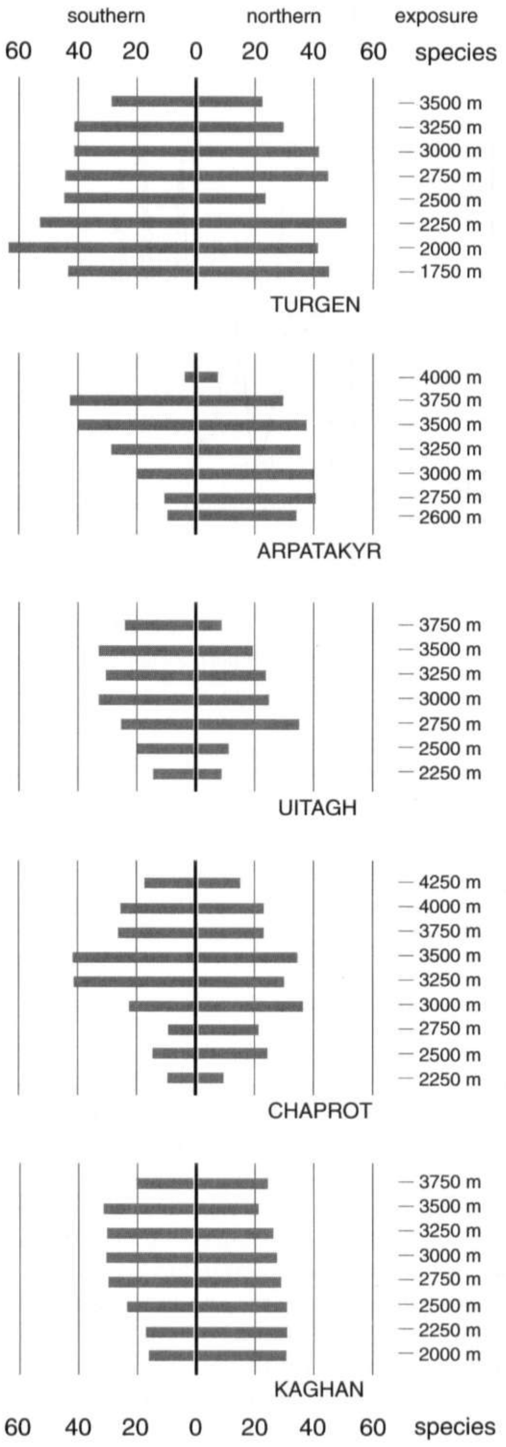

Fig. 5: Number of species in the summarized sample plots per altitudinal level and in dependency upon the two extreme exposures in the five investigation areas

Artenzahlen auf den jeweils zusammengefaßten Testflächen pro Höhenniveau und in Abhängigkeit der beiden Extremexpositionen in den fünf Untersuchungsgebieten since Neelam Valley, following south, is situated in the restricted area of Azad Kashmir and since parts of Kohistan adjoining to the north are considered to be dangerous. Thus, as an exception, the data collections are presented in a V-profile (Fig. 6).

The lower Kaghan Valley is characterized by a dense vegetation according to humid climatic conditions. In both exposures, tall pine-dominated forests prevail under semi-natural prerequisites (see map and profiles in SCHICKHOFF 1993 and 1996). The greater humidity is caused by summer monsoon and frontal winter precipitation causing a surplus in the water regime in the cool season (WEIERS 1995). The vertical sequence starts with light coniferous forests of fire-resistant *Pinus roxburghii*, similar to forests of *P. canariensis* in the upper part of the fog-induced belt of the Canarian Islands. Both communities have a need for additional summer precipitations given by trade winds in the latter and by monsoon in the first case. However, in the warm season the part of Kaghan at altitudes below approx. 2600 m must be considered as unfavorable dry due to increased evaporation rates. Therefore, mediterranean conditions prevail here, which are represented in mixed forests which contain trees like the sclerophyllous oak *Quercus baloot* as well as Himalayan Cedar *Cedrus deodora* resembling the semi-humid meso- to supramediterranean levels in the Middle Atlas or Lebanon Mountains. Higher up, dark coniferous forests follow containing *Pinus wallichiana*, *Abies pindrow* and *Picea smithiana*, which can be assigned to an alpine altitudinal sequence rather than to a mediterranean one in its humid higher-elevated sections.

The similarity analyses indicate that vegetation equalizes (Fig. 6, bottom left corner), at least if the values are revalorized by coverage rather than syntaxonomic spectra, as altitude increases. However, two residuals at 2250 m and 3250 m show considerable differences in the formation between both slopes due to anthropogenic effects like intense agricultural and pastoral activity. Therefore, the dotted line describes the actual and the continuous line the potential trend. In addition, the principal vertical equalization is clearly recognizable in the cluster: while in the higher elevations around 3500 and 3750 m the plant communities of the northern and southern slopes meet at a level of high similarity (Fig. 6, dendogram on the left) the moderate and lower elevations show stronger differences of exposure and altitude (e.g. narrower bundles for the levels from 2750 to 3250 m at the southern exposure and from 2500 to 3000 m at the northern exposure).

However, the differences of vegetation caused by exposure in the intermediate altitudes depend on vertical displacement of altitudinal belts rather than on differences in the species potential. Here, in the area of the subalpine coniferous forests according to associations determined by SCHICKHOFF (1996), the fir stands at the north-facing slopes can be separated from the pine stands at the south-facing slopes though the two name-giving character trees occur in both exposures. *Pinus wallichiana* covers a higher climatic-ecological amplitude than *Abies pindrow*. Furthermore, a lot of under-storey plants indicate different vertical distributions depending on exposure: *Adiantum venustum*, *Dryopteris stewartii*, *Androsace rotundifolia*, *Fragaria nubicola*, *Lonicera govaniana*, *Polygonum amplexicaulis*, and *Viburnum grandiflorum* start at lower elevations on shaded and ascend to higher altitudes on sunny slopes.

In the profile, only the south-exposed lower elevations around 2000 and 2250 m differ clearly from conditions at the north-exposed slopes (Fig. 6, cluster on the right). This might be based on a natural background like variations in humidity due to increased evaporation rates in southern positions, but seems to be principally caused by anthropogenic influences. Up to scarcely 2000 m, *Pinus roxburghii* is found to be the dominant tree species both on sunny as well as on shaded exposures, even here supporting the elevation differences theory rather than that one of exposure contrasts.

Therefore, in the lower Kaghan an exposure-caused displacement of altitudinal belts exists; however, no pronounced species contrasts are present. This feature supports the above-mentioned idea of prevailing humid conditions in the area. The recognizable displacement in the profile suggests thermic differences, which are typical effects for climates of the subtropical-tropical transition, characterized by torrential rains on the one hand, and generally high solar radiation on the other.

6.2 *Chaprot/Karakoram*
(36°15' N, 74°15' E; Fig. 7, Suppl. II)

In the Karakoram the weather can be influenced by extratropical western air flows even in summer, whereas in the valleys, heavy precipitation occurs most often in late winter and spring but only occasionally in August and September. The conditions change with higher elevations, where, according to WEIERS (1995), convective processes lead to a salient self-sufficiency of the summer precipitation regime, which probably results from the convergence of unstable moist air masses from the S-SW ascending from the Indus lowlands with winds from the NW in the altitude (FLOHN 1969). These summer precipitations cause not only the considerably increasing vertical gradients in the Karakoram

(MIEHE et al. 1996), but the intensive glaciation of the mountainous area within its dry base (OWEN a. DERBYSHIRE 1989) as well.

The steep gradient of humidity is clearly visible in the statistical analyses from the Chaprot area in Figure 7. In contrast to the Kaghan Valley, the syntaxonomic similarity curve starts now from a high value, which mainly results from the superimposing aridity as a substantial feature of the vegetation on the downslopes. Up to approximately 2600 m, a semi-desert dominates in transition to dwarf scrub steppe, where first *Kochia prostrata*, then *Artemisia brevifolia* with *Juniperus semiglobosa* and *Heteropappus altaicus* show a high presence.

At medium altitudes, open woodland of juniper still prevails at approximately 3000 m on the south-facing slopes, accompanied by shrubby *Berberis orthobotrys, Lonicera microphylla, Ribes orientale,* and *Rosa webbiana.* In contrast, on the north-facing slopes a distinct vegetation with dark coniferous forests of *Picea smithiana* and relics of *Pinus wallichiana* predominates; *Cicer microphyllum, Fragaria nubicola, Viola rupestris, Orthilia secunda, Carex oligocarya, Bromus confinis,* and *Festuca hartmannii* play an important role in the ground layer. At the Tallum Crest between the Chaprot and Rashumaling Valley, the contrast remains obvious at a level around 3500 m (Fig. 8), where *Leontopodium campestre, Nepeta discolor, Thymus linearis, Koeleria cristata* and *Juniperus turkestanica* predominate the southern exposures and coniferous forests on the northern exposures are leading into deciduous forests of *Betula utilis* with *Sorbus tianshanica,* including *Bergenia stracheyi, Epilobium angustifolium,* dense carpets of *Geranium pratense ssp. stewartianum, Pyrola karakoramica,* and *Vicatia wolffiana* in the herb layer.

Even for the transition from the subalpine to alpine belt, HARTMANN (1972) proves major exposure differences by stating *Salix karelinii* bushes in the Braldo and Biafo Valley only on the shady slopes. However, in the Chaprot Valley this willow occurs scattered across sunny slopes, too, accompanied by *Juniperus communis ssp. alpina* and the constant *Saxifraga sibirica.* Similarity values are finally increased at higher elevations dominated by the Cyperaceae *Kobresia capilliformis, K. nitens,* and *Carex stenocarpa,* interspersed with *Potentilla venusta, Gentiana cf. marginata,* and the widespread *Bistorta affinis.* The renewed resemblance of the plant communities on contrary slope exposures is now due to humid conditions, added by superimposing ecological factors, such as frequent freezing during the vegetative period and a long period of soil-water saturation by melting of the snow. As the valleys of Braldo and Biafo are already situated in the more arid Central Karakoram (MIEHE et al. 1996), the contrasts of vegetation extend higher up into the alpine level.

Thus, in the dendrogram only the vegetation of the differently exposed sites of the lower positions (left) and the higher positions (right) are bundled to similar plant communities. At intermediate altitudes, however, the northern and southern slopes at elevations of 3000 to 3500 m are separated by far linkages and require a differentiation of the communities. The spruce-pine and birch-mountain ash forests are posed in some isolation, containing species that prefer mesic moisture regimes such as *Fragaria nubicola, Geranium pratense* or *Orthilia secunda.* According to CRAMER (1997) these slopes are characterized by a hibernal deficit of radiation resulting by a long period of snow cover.

Distinct altitudinal belts within the lower and upper area separated by obvious differences of exposures in the middle part indicate the vertical change from arid to humid climatic conditions. The humidity pattern appears despite a quite strong human influence. BRAUN (1996) presumes a total decrease of 75% of the natural forest coverage, referring to the last 30 years for the Chaprot area. Nevertheless, the hygrothermic contrasts between north- and south-facing slopes are influencing a synanthropic vegetation, too. More detailed remarks by MIEHE et al. (1996) from the comparable Bagrot Valley support this assumption. SCHICKHOFF (in print) presents more detailed phytosociological lists of pine and spruce-forests in Chaprot.

6.3 Oytagh/Kunlun
(38°55' N, 75°05' E; Fig. 9, Suppl. III)

Climatic-ecological experiences from the Oytagh in the Aksaibashi Mountains of the northwestern Kunlun are still lacking. The restricted area near to the Tadjik border has been closed to foreigners until recently and only poor topographical maps were available for more exact orientation. Thus, the "discovery" of a rapid change of humidity from sub-arid conditions at the lower valley to sub-humid belts in the upper valley is particularly remarkable (arrow in Figs. 4 and 12).

Thus, a transition zone from the Chenopodiaceae semi-desert crossing an open juniper forest up to a dense spruce forest over a distance of scarcely 5 km can be identified (assembled profile in Fig. 9). It is noticeable that in the Oytagh, in contrast to the Tian Shan and Karakoram, spruce stands are even found on south-facing slopes. This situation might likewise occur in further glaciated valleys at the eastern slopes in the Kongur Massif (SKRINE 1926) and in more distant areas like that one in the area southeast of Pik Pobeda (Fig. 3, top).

Within the lower area, however, aridity causes an adjustment of the vegetation at the 2000–2250 m level just like in the Chaprot (not necessarily of species, as illustrated by the complete circles). Beside *Sympegma regelii* and *Kalidium cuspidatum*, *Tetracme quadricornis* and *Plantago minuta* occur constantly. According to DICKORÉ (1991) the species mentioned first is typical for the montane edge of the Taklamakan. The transition from semi-desert to scrub steppe with *Artemisia brevifolia* and *Juniperus semiglobosa* in the upper valley of Oytagh and particularly of Atoynak shows affinities both with the Karakoram and the southern Tian Shan.

Only in the lower part of the dark coniferous forests do major exposure-conditioned vegetation contrasts occur. At an elevation of approximately 3000 m they are characterized by the differentiation between sagebrush-juniper stands still dominating the sunny slopes and the spruce forests with a coverage up to 50 % at shady sites with *Picea schrenkiana* ingressing from the north. The latter indicate elements of the southern investigation areas in the understory (*Lonicera heterophylla, Salix iliensis* or in the herbaceous layer *Orthilia secunda*) as well as of the mountain ranges in the north (i.e. *Salix schugnanica, Vicatia coniifolia, Geranium cf. saxatile, Carex turkestanica*). Within this narrow belt of the lower forestline extending only approximately 300 m in a vertical direction, a rapid semi-arid to semi-humid transition takes place.

At 3250 m the contrast of species is once more removed to a large extent, since mesic species such as *Salix iliensis*, *Polygonum cf. viviparum* and *Dracocephalum imberbe* also pass over to the south-facing slopes and only few xerophilous representatives such as *Potentilla bifurca* and *Isopyron anemonoides* remain concentrated on the sunny side. Starting from this level, increasing humidity must be considered the only explanation for the floristic similarity of the two exposures. The cause might be the cirque position of the steep valley end, which is filled by a large glacier situated below the NE-headwall of Kara-Bahtiyar. In the surroundings of the tongue reaching down to 2700 m those spruce forests grow, which profit in particular from the frequent local summer afternoon rainfalls (see above).

The crests receive a surplus of precipitation, too, even though the decreasing coverage of vegetation with increasing altitude seems to contradict this theory. However, this trend reflects the strong solifluidal landform changes: a rapid shifting of altitudinal zonation (Fig. 4, arrow) indicates that this complex as well as probably all other glaciated valleys of the eastern escarpment of Kunlun are characterized by bound solifluction extending down to 3200 m, contrary to the dry breached valleys of Gez or Taxkourgan without this periglacial type but with patterned ground above 3900 m (FICKERT 1998). Thus the vegetation with species like *Kobresia karakorumensis*, *Androsace flavescens* and *Saxifraga pulvinaria* scarcely ascends to more than 3750 m due to very active cryogenic processes and rocky summits between Oytagh and Atoynak. As in the two preceeding examples but differing from the following one, the jagged arêtes and pointed horns prove Quaternary sharpening and disprove a forming of south-facing slopes by large-scale denudation of frost debris in bare blockfields under semi-arid conditions. This feature once more supports the hypothesis to classify the subnival belt as humid.

6.4 Arpatakyr/Kuiljutau
(42°11' N, 79°01' E; Fig. 10, Suppl. IV)

The example of Arpatakyr towers up to a high plateau in 3700 m with a relative relief of approximately 1100 m between the river of Kuilju and Malenkij Taldysu. The areas below 2600 m, situated in the restricted area near the borderline with China, remain unconsidered in the investigation. Most likely a Chenopodiaceae semi-desert, comparable with the lowest part of Kunlun exists there.

Situated between Terskeij Alatau and Kokshal Alatau, the Kuiljutau is located in the described double lee position, but the high plateau forms an extended site with a dense *Carex melanantha* fen. Although situated in a relatively dry climate, mesic representatives such as *Trollius lilacinus* and *Erigeron aurantiacus* indicate moist conditions, most probably caused by a discontinuous permafrost layer, as might be concluded by arguments of GORBUNOV (1978). This sedge floor is interrupted by gaps containing a moss carpet with *Cyrtomnium cf. hymenophyllum* (Mniaceae) as well as further hygrophilous species like *Pedicularis maximoviczii* and *Ranunculus alberti*. Furthermore, dispersed pools without vegetation occur that might normally be filled with water (according to previous photographs by V. SGIBNEV, Cologne). However, they were dried up completely during our sojourn in July 1997. These topographically and edaphically azonal communities that resemble the well described "naka" bogs of V. WISSMANN (1961) in Northern Tibet, remain unconsidered in Fig. 10.

At the northern exposures, open spruce forests can be found in valley positions from 2600 to 3100 m despite low precipitation around 300 mm/a. They consist of brightly-needled, hardly 10 m tall *Picea schrenkiana*. In combination with the shrub-like *Salix alatavica* and *S. argyracea* or with *Poa nemoralis*, these spruce forests resemble a hygrophilous community. In contrast, the associations with *Caragana pleiophylla* and within the lower belts also with the blueish dwarf shrubs *Artemisia tianshanica*, *A. frigida* and *Eurotia ceratoides* indicate a more xerophilous aspect. *Juniperus pseudosabina*, which is frequent on the moister north-facing side of nearby Terskeij Alatau, does not occur at Kuiljutau.

At the south-facing slopes, an open steppe consisting of *Artemisia brevifolia, Stipa capillata Agropyron cristatum, Potentilla patens* and *P. conferta* becomes denser with *Festuca tianschanica* and *Poa alpina* above 2900 m. In spots, vegetative sprouts of the circularly-growing grass *Psathyrostachys juncea* indicate a mosaic cycle. Above approximately 3200 m, the three latter grasses are strongly restricted by closed, bushless carpets of the Cyperaceae *Kobresia humilis* and *Carex stenocarpa*. Colourful flowering herbs are represented by species as *Astragalus aksuensis, Oxytropis savellanica, Ligularia alpigena* and *Rhaponticum cf. serratuloides*. Below 3700 m, similarities between southern and northern slopes remain few except for some overlapping grasses like *Helictotrichon tianschanicum* and *Trisetum spicatum* or the forbs *Gentiana falcata, Swertia marginata* and *Polygonum viviparum*. The presence of the monocots *Carex titovii, Kobresia capilliformis* and *Festuca alatavica*, as well as of the dicots *Schultzia albiflora, Gentiana fetissowii* and *Chrysosplenium nudicaule*, is limited to the shady slopes.

At 3750 m, overlapping species from the north-facing slopes, like *Oxytropis merkensis, Potentilla multifida* and *Dracocephalum integrifolium*, contribute to a floristic equalization of the exposures, as well as the species invading from the fens like *Erigeron aurantiacus, Trollius lilacinus, Saxifraga hirculus* and *Gentiana algida*. The predominant grass on shady slopes is *Festuca kryloviana*, whereas *Kobresia* and *Carex* remain abundant on sunny slopes. The coverage at 3750 m still ranges between 60 and 90%, but decreases rapidly at higher altitudes to a few patches. At an altitude of 4000 m, only some dwarf species like *Chorispora bungeana, Saussurea gnaphalodes* and *Saxifraga stenophylla* survive. In the transition to this solifluidal formed subnival belt the cushion- and garland-formed *Sibbaldia tetrandra* is notable. This Rosacea is considered as a characteristic species of the subnival level from 4400 to 5000 m in the extremely dry Kunlun south of the Tarim Basin (DICKORÉ 1991). It should also be mentioned that in the Arpatakyr at 3800 m, a maximum temperature of 72°C was measured on 24.7. 97 at 1 p.m. on the mor-surface of the same species.

The dendrogram presents a similar, exposure-independent species composition only at the upper limit of the vegetation. Up to this altitude the groups of south- and north-facing communities show considerable contrasts in the cluster (similarity indices). The life-form spectra underscore the low similarity of the vegetation between the two exposures.

Thus, the analyses indicate climatic conditions different from those in Oytagh: at the toe the aridity of the semi-deserts south of the Arpatakyr area might result in an increased similarity, as the lowest trend of the curve in the similarity diagram suggests. At the Kuiljutau the dissimilarity refers to a broad semi-arid to semi-humid transition, which extends higher than in the Oytagh. Similarities occurring at the 4000 m-level can be explained by a late melting of snow rather than an increase of precipitation. So a semi-humid, maybe even a semi-arid climate is likely to prevail into the summit regions, as the distinct frost debris in bare blockfields at the southern sides underscores, in contrast to the strongly glaciated northern sides of the summits.

6.5 Turgen/Sailijskij Alatau.
(43°14' N, 77°37' E; Fig. 11, Suppl. V)

This solifluidal slope denudation, typical for the Terskeij and Kungeij Alatau, recedes in the Sailijskij Alatau (SCHRÖDER et al. 1996). Instead, a glacial sharpening of the summits dominates at all exposures, so that a relatively humid climate is expected. The available precipitation values actually range between 600 mm/a in the foreland at Almaty and 1000 mm/a in some mountain sections at the northern escarpment (Fig. 2). Until midsummer the belt of a maximum input moves upwards, due to a supply of moist air masses from the Kaspi Basin.

Despite increasing precipitation values, the southern exposures are not wooded in the Sailijskij Alatau (Fig. 11), apart from the occurrence of shrublike *Juniperus pseudosabina* above approximately 1700 m. However, on northern exposures dense dark coniferous forests with *Picea schrenkiana* and interspersed *Salix iliensis* are present between 1700 and 2900 m. An anthropogenic depression of the treeline due to pasturing on the south-facing sides is to be excluded: where small hills or ridges jut out of the same slopes, stands of spruce forest occur immediately at the respective northern exposure; these stands would not have outlasted an overall intense human intervention on the sunny side of the valley. Mowed grass-steppes of *Brachypodium pinnatum* or *Dactylis glomerata*, as they are reported by WALTER a. BRECKLE (1994) from the Kungeij Alatau, are absent in the investigation area.

However, a missing spruce forest is not inevitably an indicator for a relatively arid climate at the sunny slopes. With approx. 1000 mm/a precipitation falling mostly during the vegetation period, due to frequent summer thunderstorms, numerous tree species could exist here without problems if they only occurred in this region! Thus, lack of tree genera must be explained by the floristic history of this region, as long as no taxa of the more distant environs were able to cross the

Kazak steppes and to immigrate into the formerly glaciated valleys (AGACHANJANC 1980; "principle of the vacant niche", RICHTER 1996). However, migration deficits do not inevitably apply to the adjacent northern mountains. According to TRETER (1996), exposure differences can be attributed to substantial moisture deficits at the southern exposures in the Mongolian Altai, while an annual precipitation of probably only 200–250 mm is sufficient for *Larix sibirica* forests at the north-facing slopes. Thus, the fact that the similarity analyses in the coordination system in Figure 11 refer to large exposure differences does not principally focus on conditions of humidity. Nevertheless, it is shown clearly that in spite of the relatively high precipitation input at all altitudinal levels the potential evaporation as the thermal component of the water balance will most likely be a major factor. It becomes even more evident eastward, where HAI-YING (1998) describes a more limited belt of *Picea schrenkiana* between 2200 and 2500 m at northern exposures of the Xinyuan Mountains in the Chinese part of Tian Shan. As mean annual precipitation at Xinyuan (940 m) reaches only 478 mm/a, in this case the accelerated aridity must be considered in contrast to the Turgen Valley as the only trigger for the syntaxonomic differences between the extreme exposures.

Though located only 150 km further north, the altitudinal belts of individual core species in the Sailijskij Alatau decrease considerably compared to the Kuiljutau. This concerns not only the upper line of *Picea schrenkiana* on the north-facing slopes descending from 3050 m down to approximately 2900 m. *Festuca tianschanica*, concentrated on the south-facing slopes, decreases even from 3300 m down to 2600 m. In these cases, the lower limits seem to be more significant for a climatic interpretation: *Festuca* does not occur below 2900 m in the Kuiljutau just as *Picea* does not descend below 2500 m, whereas both species are found still at 1700 m in the Turgen Valley. In particular, these differences in the lower distribution of more than 1200 m of *Festuca* clarify the higher degree of humidity of the foreland in the Sailijskij Alatau. In contrast, its restricted area in the Kuiljutau is caused by dryness (replacement there by the xerothermous *Artemisia brevifolia* and *Stipa regeliana*). Equally informative is the high concentration of *Carex titovii* on south-facing slopes in the Turgen Valley (1700–2900 m), whereas it is limited at the Arpatakyr to north-facing slopes (2600–3600 m). Therefore it might be assumed that a northern exposure around 3100 ± 500 m at the Sailijskij Alatau corresponds hygrically to a southern exposure around 2300 m ± 600 m at the Kuiljutau. Concerning *Festuca kryloviana*, occurring at higher altitudes, a similar transfer in altitude and exposure corroborates this hypothesis. The considerations point out that the Turgen Valley is, as expected, a lot moister than the Arpatakyr area: from the valley bottom up to the crest, the north-facing slopes might remain sub-humid and the south-facing slopes semi-humid.

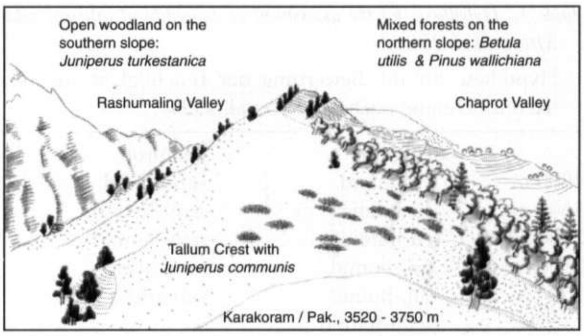

Fig. 8: Vegetation contrasts between southern and northern exposures at 3500 m; Tallum Crest/Chaprot

Vegetationskontraste zwischen Süd- und Nordhang bei 3500 m am Tallum-Kamm/Chaprot

Some eurasiatic elements like *Poa pratensis*, *Bromus inermis* and *Galium verum* are restricted to the valley's sunny side up to 2500 m. However, compared to the other Central Asian mountain ranges numerous species comprise wider vertical spectra in the Turgen Valley. This explains why in this case the subalpine belt covers an altitudinal distance of approximately 1000 m and the alpine belt at least 800 m (Fig. 11, top). Among the widespread subalpine elements of mountain steppes *Carex titovii*, *Festuca tianschanica*, *Allium turkestanicum*, *Eremostachys speciosa*, *Potentilla bifurca* and *Spiraea hypericifolia* are frequent on the sunny slopes. Upwards, the alpine *Kobresia humilis*, *Festuca vallesiaca*, *Elymus tschimganicus*, and *Androsace septentrionalis* must be considered as core species.

At these levels between 2750 and 3500 m, several highly constant species like *Festuca kryloviana*, *Thalictrum alpinum*, *Geranium saxatile*, *Pedicularis oederi*, *Lagotis integrifolia* and *Leontopodium leontopodinum* are common in both extreme exposures. Concentrated on shady slopes of the same altitudinal belt are the grasses *Kobresia capillifolia*, *Carex stenocarpa* and, further up, *C. melanantha* as well as the herbs *Vicatia coniifolia*, *Chrysosplenium nudicaule*, *Viola altaica* and *Polygonum viviparum*. In the subalpine spruce forests at north-facing slopes the ombrophilous grass *Poa nemoralis* with the tall forbs *Lathyrus gmelinii*, *Polemonium caucasicum*, *Stellaria brachypetala*, *Aegopodium alpestre*, *Polygonum nitens*, and *Cicerbita azurea* are restricted to the under-storey. Only few species occur in the forests as well as in grassland: *Trollius dshungaricus*, *Papaver croceum*, and *Geranium albiflorum* ascend from the

Table 1: Hypothesis for the assessment of humidity at different altitudinal levels in the mountain ranges investigated (designation according to MIEHE *et al. 1996)*

Hypothese für die Bewertung der Feuchtigkeit auf verschiedenen Höhenstufen in den untersuchten Gebirgsgebieten (Kennzeichnung nach MIEHE et al. 1996)

	Kaghan	Chaprot	Oytagh	Arpatakyr	Turgen
4000 m	eu-humid	sub-humid	eu-humid	semi-humid	eu-humid
3500 m	eu-humid	semi-humid	sub-humid	semi-humid	sub-humid
3000 m	eu-humid	semi-humid	semi-humid	semi-arid	sub-humid
2500 m	sub-humid	semi-arid	semi-arid	sub-arid	sub-humid
2000 m	sub-humid	sub-arid	sub-arid	—	semi-humid
1500 m	semi-humid	—	eu-arid	—	semi-humid
gradient:	low	intermediate	high	low	low

spruce into the mat zone; *Galium octonarium, Sedum hybridum*, and *Euonymus semenovii* are to be found under coniferous stands as well as in steppe sites.

Thus, salient exposure differences are typical for the northern Tian Shan area. In contrast, altitudinal zonation remains less perceptible, as rather homogeneous communities are widespread over a long vertical distance due to weakly pronounced differences in humidity. The dendrogram illustrates this fact by a floating vertical sequence of the relevés, i.e. all southern-exposed sites are located in the cluster on the left and all northern-exposed on the right half. Only in the centre the opposite sample plots at 3500 m testify similar climatic-ecological specifications. The contrasting life-form spectra and the profile differentiation within the profile are evidence of these features.

7 Conclusion

Summarizing and comparing the results of the regional investigations, concerning the status of humidity based on the similarity analyses, the following picture results:

Table 1 illustrates the following principles, completed by further observations:

– Above 4000 m, humid conditions are present almost everywhere. In the alpine belt this approximation is reflected by mats with *Kobresia capillifolia*, occurring in all five areas, or *Carex stenocarpa, Poa alpina* and *Festuca alatavica* in most of the cases. However, some mountain ranges in the Tian Shan show decreasing precipitation values at higher elevations (Kuiljutau).

– The southern edge of the profile (Kaghan) is defined by sub-humid conditions caused by precipitation generated by the subtropical monsoon in summer, even at lower altitudes. Likewise the northern edge (Turgen) is relatively humid at northern exposures. Both valleys share some species that are missing in the central arid mountain regions, for example *Viola biflora* at the respective timberline ecotone and *Rhodiola coccinea* in the upper alpine mats.

– Instead of the low change of humidity at these two more humid "corner points", the vertical gradient of precipitation in the Chaprot and Oytagh is characterized by a strong increase of humidity within short distances. In the first case this change takes place within a few hundred meters. In the driest mountain areas, for instance at the Kongur above the Bulunkul Plateau, the vertical gradient of precipitation might be poor again, since it remains dry up to the highest elevations (eu- and per-arid climates; interior continental type of gradient in Fig. 2).

– The type of a particularly rapid vertical change in the Oytagh is probably limited to valleys ending in glacial cirques, as it is the case in the Western Kunlun at Kara-Bahtiyar and in the Southern Tian Shan at Pik Pobeda. In both regions dark coniferous forests with *Picea schrenkiana* are indicators for "moist islands".

– Breached valleys, which run out on plateaus (e.g. those of Bulunkul and Taxkourgan between Kunlun and the Sarykol Mountains in the Eastern Pamir or the Syrte around Torugart), are characterized by stormy upwinds during the day, which impede a local precipitation genesis and cause dryness, for instance in the Gez and Aksay Valley.

– The direct neighbourhood of arid breached and humid glacial valleys requires a more detailed small-scale differentiation for developing thematic profiles or overview maps marking the position of phytogeographical and geomorphologic altitudinal belts (arrow in Figs. 3 and 12). However, contrasting features might be clarified by the study of the orographic situation shown in topographic maps like the Russian 1:500 000 and from satellite photographs.

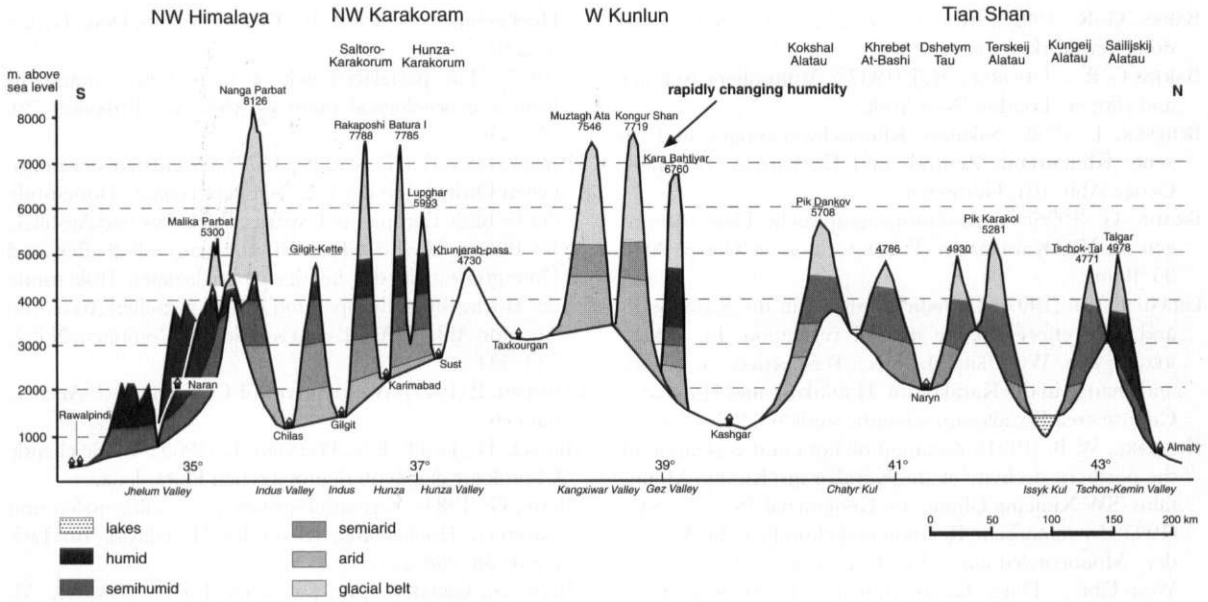

Fig. 12: Assumed sequence of the vertical and meridional change of the conditions of humidity in the western part of High Asia

Vermutete Abfolge des vertikalen und planetarischen Wandels der Humiditätsverhältnisse in einem Meridionalprofil durch das westliche Hochasien

– The "principle of the vacant niche" with the example of *Picea schrenkiana* in the Sailijskij Alatau does not mean that this spruce species avoids south-facing slopes in general. It occurs on those sites in the Oytagh, so that in its valley end the amount of precipitation may exceed 1000 mm/a.

– In the sense of AGACHANJANC (1985), mountains with an obvious vertical zonation without specific vegetation contrasts caused by exposure can be separated from those, where vegetation contrasts caused by exposure are stronger than vertical zonation. Cluster analyses illustrate this phenomenon by the respective bundling of northern and southern-exposed sites (Fig. 11; the same applies to the western and eastern side of the Sierra Nevada in California, HETZNER et al. 1997). Dendrograms of the Western Himalaya and Kunlun exhibit a more strongly marked zonation of altitudinal belts by more distinct differences between northern and southern-exposed sites (in an analogous example of the White Mountains in California these changes are quite regular).

– The vertical expansion of the altitudinal belts is particularly wide in the northern Tian Shan with a distribution of many core species covering an relative altitude of 1000 m. Here, the poorly differentiated sequence of belts can be explained by rather balanced conditions of humidity.

– It can be derived that regarding β-diversity heterogeneity within mountains with a dry foreland is high and in those with a moister one it is low. Furthermore, β-diversity probably decreases in the profile from High to Central Asia. With respect to α-diversity and β-turnover, in the case of the mountain-profile from western High Asia to Central Asia floristic history seems to be more important than climatic-ecological triggers.

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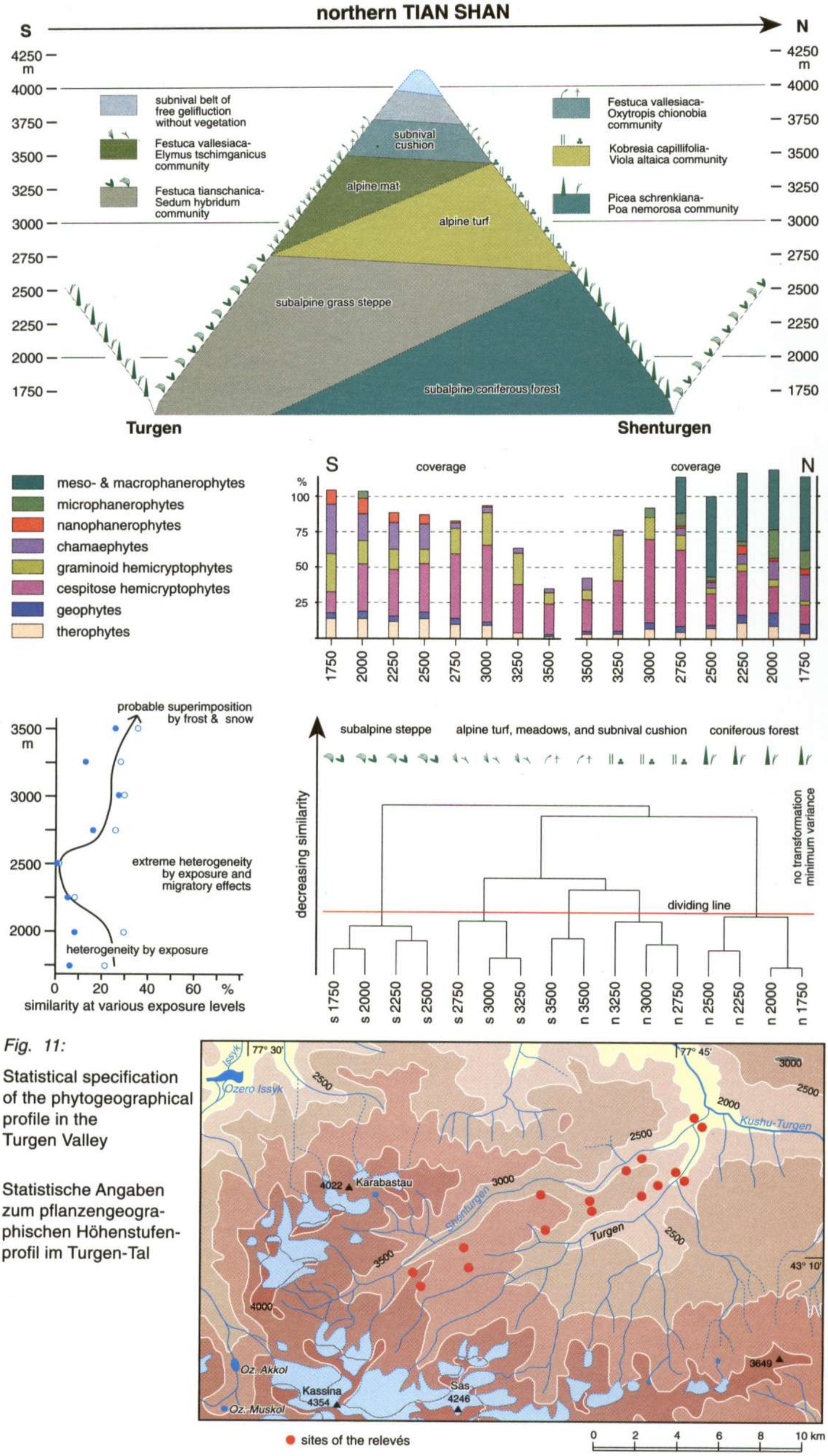
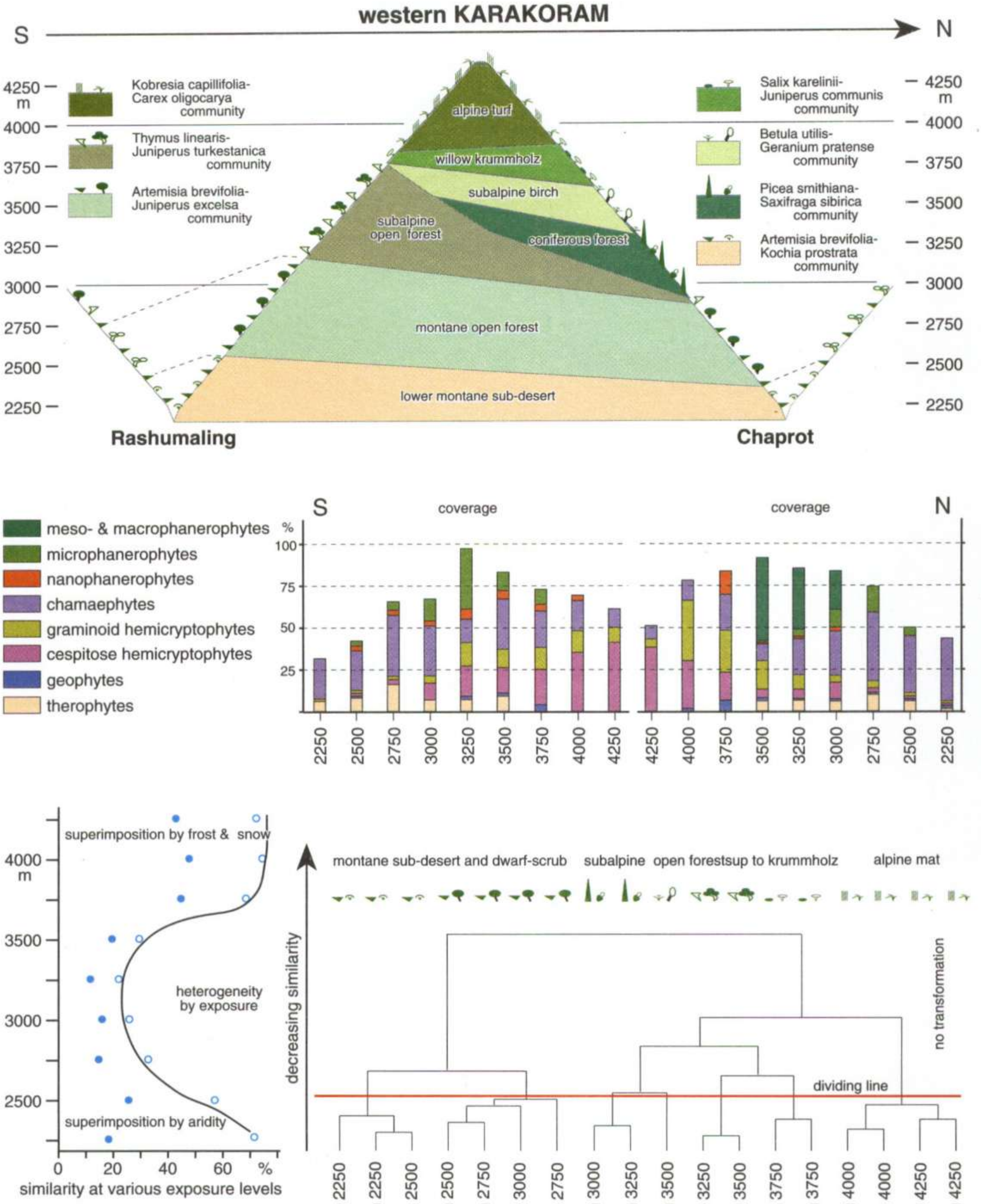


Fig. 11:

Statistical specification of the phytogeographical profile in the Turgen Valley

Statistische Angaben zum pflanzengeographischen Höhenstufenprofil im Turgen-Tal

Beilage II zu ERDKUNDE 53,2 Beitrag RICHTER/PFEIFER/FICKERT



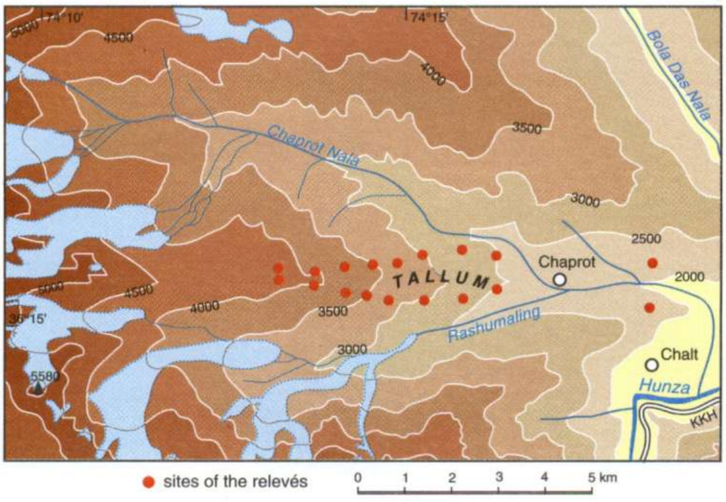


Fig. 7:

Statistical specification of the phytogeographical profile in the Chaprot Valley

Statistische Angaben zum pflanzengeographischen Höhenstufenprofil im Chaprot-Tal

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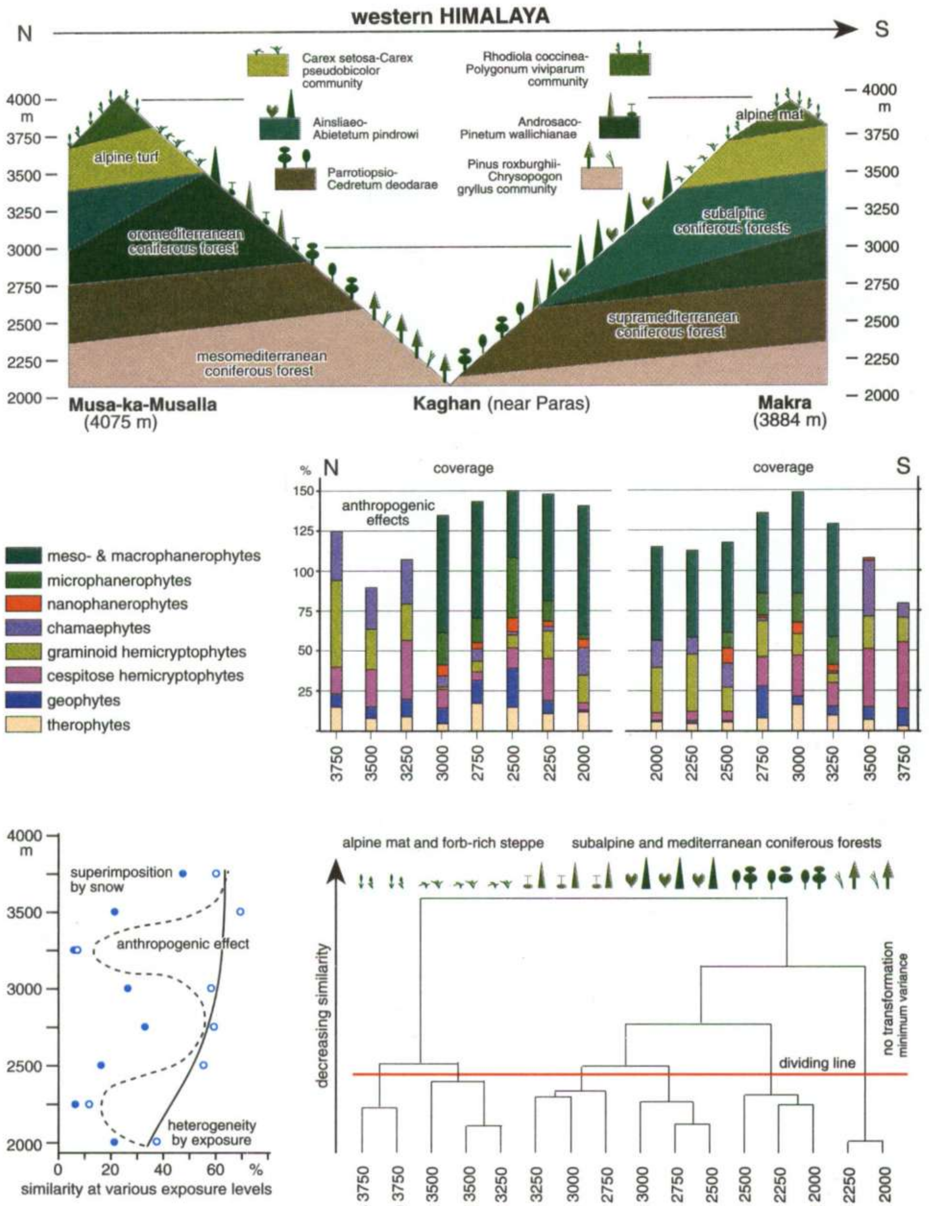
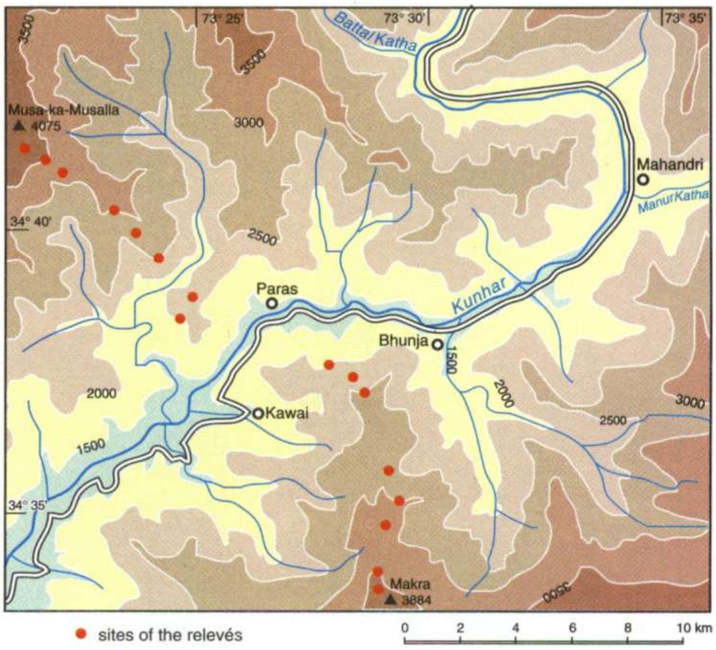


Fig. 6 :

Statistical specification of the phytogeographical profile in the Kaghan Valley

Statistische Angaben zum pflanzengeographischen Höhenstufenprofil im Kaghan-Tal



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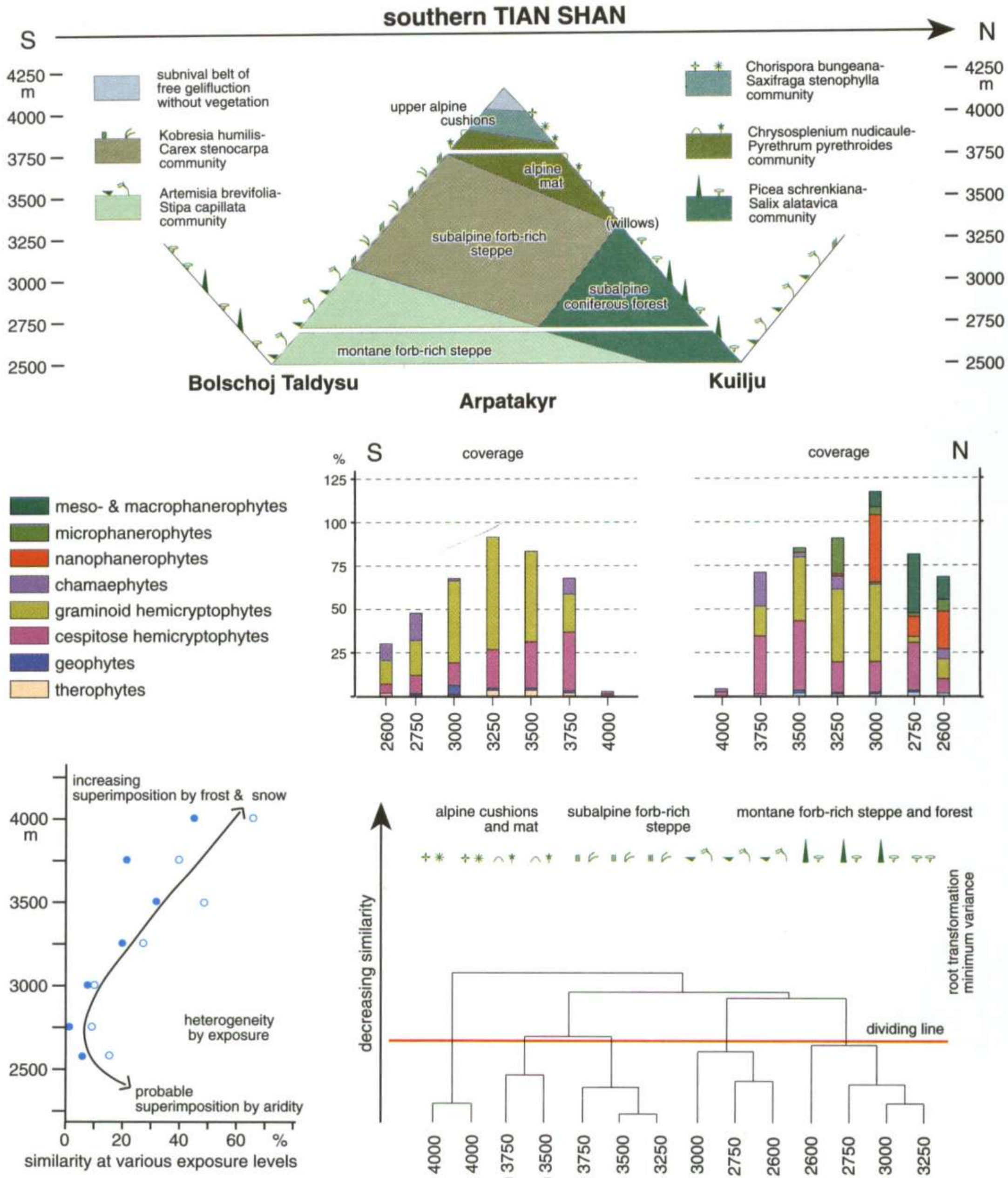
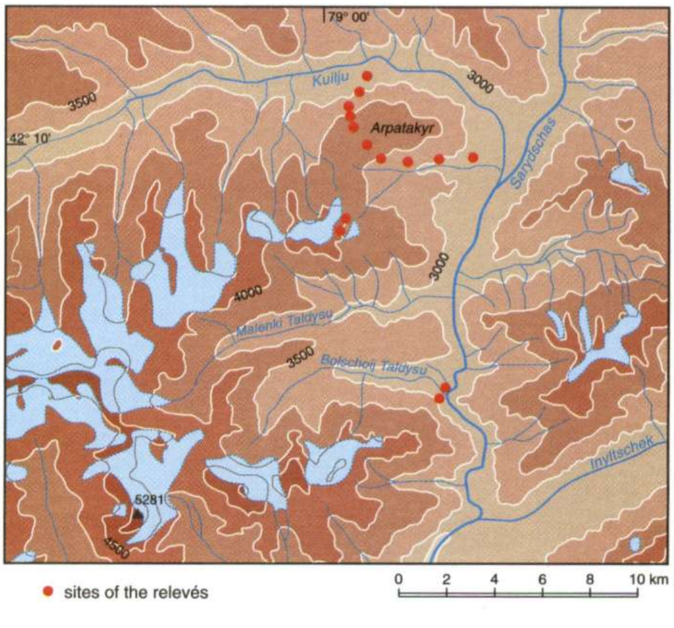


Fig. 10:

Statistical specification of the phytogeographical profile at the Arpatakyr

Statistische Angaben zum pflanzengeographischen Höhenstufenprofil am Arpatakyr



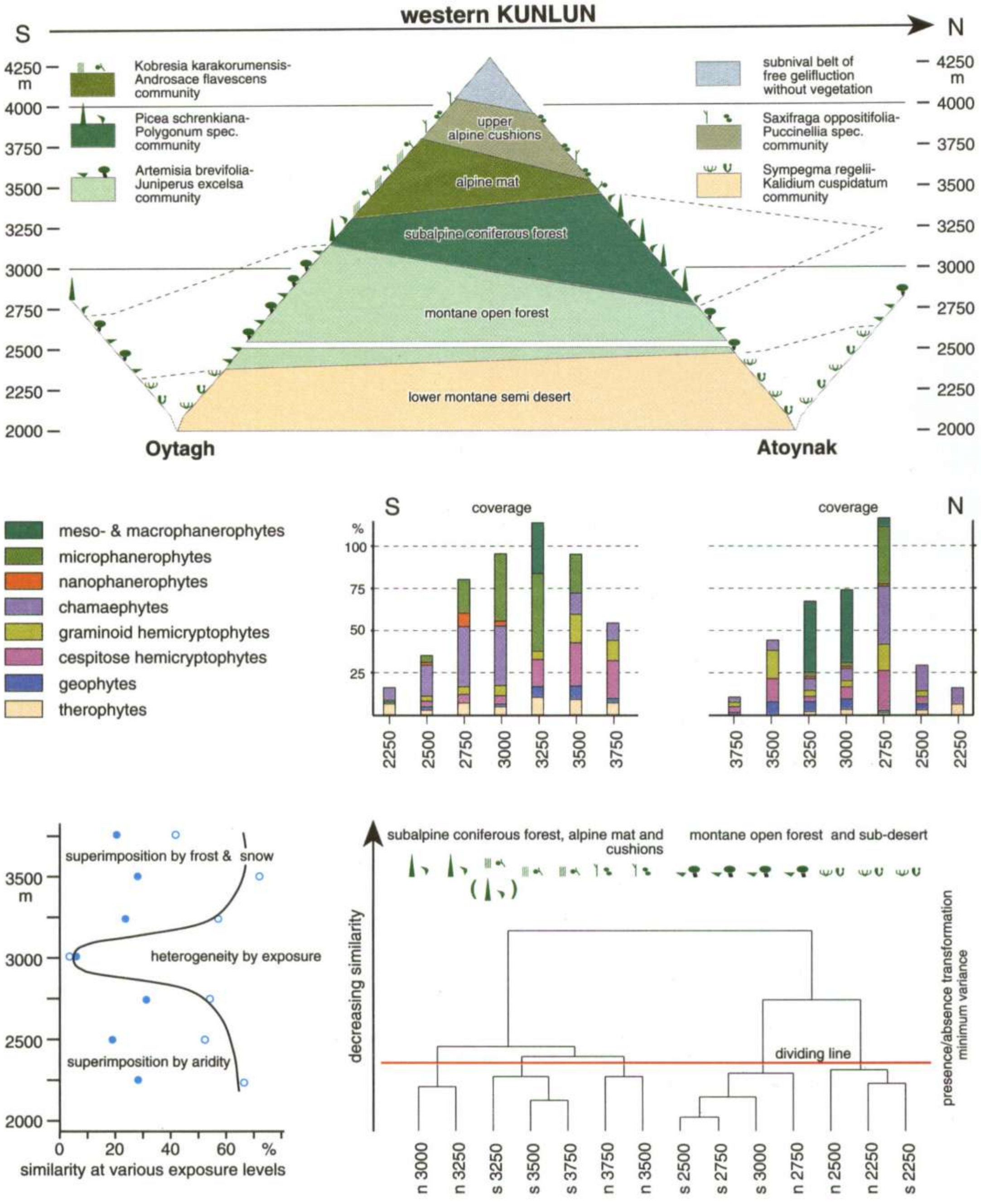
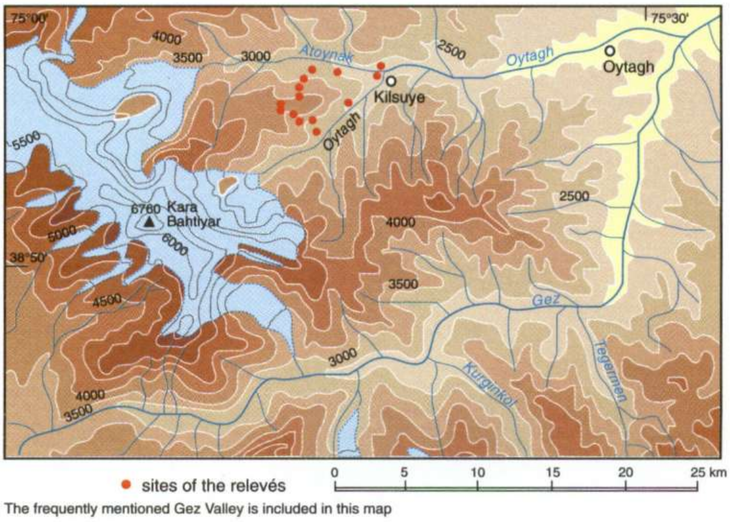


Fig. 9:

Statistical specification of the phytogeographical profile in the Oytagh Valley

Statistische Angaben zum pflanzengeographischen Höhenstufenprofil im Oytagh-Tal



The frequently mentioned Gez Valley is included in this map