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The Probability of Proof in Geomorphology – an Example of the Application of Information Theory to a new Kind of Glacigenetic Morphological Type, the Ice-marginal Ramp (Bortensander)*

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ABSTRACT: The scientific acceptance of presentations of proof is largely dependent upon the parts of mathematical logic upon which they are based. This explains the trend of introducing quantitative methods into those disciplines which – due to the historical dimensions of their subjects – have so far followed a qualitative analysis of character coincidences i.e. a typogenetic form of reasoning. But the application of reductionistic quantification such as was followed in the GMK 25 project foundered because of the polymorphic structure of the phenomena. It was this that made geomorphological proof so difficult, since an inductive basis for general lawful relations can only be provided by regionally detailed observations of complexes with developments of their own. The application of information theory however e.g. in relation to the glacigenetic Type 'Bortensander' or ice-marginal ramps (IMR)) now allows the determination of the probability of the coincidental occurrence of characteristics and a measure of the probability of the causal nexus upon which this is based. By transposing the basis of induction on to an abstract plane a high degree of proof of typogenetic arguments in geomorphology may be provided. The quantification here does not count the elements of the proof directly but is related to the occurrence of those indicators which form the empirically based qualitative units of the inductive key.

The Type in the Hierarchy of Scientific Ideas

The determination of exact ideas and unequivocal definitions to form the framework of each science was already dealt with 2400 years ago by Socrates of Athens (469–399 BC) using the maieutic method. Scientific argument as the result acquired a fixed terminology for comprehension and re-examination.

According to Carnap (1976: 59) the concepts of science can be divided into three groups; classificatory, comparative and quantitative, the latter facilitating the highest attainable degree of explanation. Since Gallileo definitive measurement provided sufficient basis for this hierarchy. Yet in fact the theories of present day natural sciences (such as heredity, continental drift or Quaternary glaciation) are based upon pure classificatory/comparative systems of ideas[1]), without their results being able to be carried over into quantitative or mathematical terms[2]). Internal to these theories there are indeed some partial aspects which are amenable to quantification – however the decision whether those quantifications are compatible with reality or not is always on the side of empiricism, i.e. the qualitative plane of empirical interrelations remains decisive for the acceptance of quantitative methods. Especially scientific subjects with historical dimensions are on a wide scope unaccessible to a quantificational formulation, since here the expression of general laws is coated by the random fixation of historical configurations and the results are an irreducible product of both of them (here the 'historical narrative' is an appropriate method; cf. Mayr 1984: 59). Analysis here must keep on a higher level of integration if its object is not to be lost. Whereas with physics a field of investigation can be made unequivocal by exact definitions of experimental arrangements and measurement techniques, in taxonomy or geomorphology, for example, polymorphic fields of similarity are built up by the processing of empirically derived correlations of cha-

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racteristics i.e. typological systems of ideas are developed (cf. Riedl 1987) with an exactitude of definition restricted by the historical or statistical variability. In the 'exact' sciences statistical variations in measured results are eliminated as disturbance factors and the calculation of 'natural constants and laws'[3] is successful. The type-concept however is based on the variability of its subjects (e.g. individuals of taxonomic units or accumulations of glacigenic processes) which by means of cognitive abstraction have to be condensed to prototypes in order to correlate them with standardising word symbols. At the same time the variability of the type must still be present because of its basic significance, for example, in the evolutionary trends of populations (Mayr 1984: 38f, 231–238) and also because the fixing of definitions would obviate the further adaption of the type to reality and thus the process of recognition would be destroyed[4]. "It is a matter of the coincidences of characteristics and the degree of variability of the characters near the boundaries of the type, although this conflicts with the logic of our linguistic thinking. – Exactness of definition deprives the typical of all polymorphic properties" (Riedl 1987: 166).

The problem at the heart of the concept of type is that 'characters' do not present themselves but must first be specified by the perception of superior units themselves derived from experienced coincidence hypotheses[5]. Character and type are thus combined in a reciprocal way such that only the breadth of observation i.e. the number of occurrences which confirm the coincidence-prognosis guarantee an increasingly optimised fit with the real world[6]. Thus the original hypothesis by which erratics in NW Germany and the Alpine foreland were attributed to a catastrophic deluge (Diluvium) became resolved into the glacigenetic hypothesis with increasing experience which has since, over 200 years of development, taken the form of a highly confirmed theory of a glacial period which has as much 'probability content' within the scientific consensus as the evolutionary theory in biology. The inherent limitations of exactness of definition in concept-formation, in which general conclusions are derived from individual, special examples (the problem of induction) as well as the obscure nature of this process of thought based on the current extent of one scientist's experience have resulted in the denigration of arguments based on typology. As a resulting reaction there has appeared e.g. in biology the 'numerical taxonomy' (Sokal; Sneath 1963) who would replace the subject related selection of relevant characteristics of traditional taxonomy by a fictitiously objective quantification method based on a normative weight equality of all characters to be analysed by computer (detailed criticism by Mayr 1984: 179 ff.; Riedl 1975: 300 ff., 310).

A similar project in geography aims at the destruction of the typological conceptual content so far derived for geomorphology by means of a symbolic key compatible with EDP which will "at the same time provide the basis for an intersubjective generally accepted language for relief (description) and fundamentals" (Barsch; Stäblein 1978: 63). The dilemma of geomorphology is here presented as the result of "a terminology lacking precision and general acceptance" for often complex ideas only subjectively defined. According to those authors there is an urgent need to develop methods of normative collection, codification, storage and output of data since otherwise "our geomorphology will be becalmed in the doldrums of an esoteric 'orchidology'" (ibid: 64). The key idea is a problem-oriented (i.e. on the needs of economy) 'relief taxonomy' such as was presented as a solution in the program for the geomorphological map of the FDR at 1:25 000 (GMK 25) detailed criticism in Kuhle 1989a, b; also cf. Klimaszewski 1988). Its principle is the disintegration of complex landscape structures e.g. the indicators of glacial morphology such as trimlines, roches moutonnées, morainic arcs) and their re-interpretation in terms of theory-neutral map symbols which are largely quantitatively or abstractly defined. The first step of this procedure of denaturalisation is the 'scale-specific typification of, relief units' (Barsch; Stäblein 1978: Tab 1) which, by means of rigid boundary values of basal length, area and height, provides an ordering of phenomena into categories of 'pico-, nano-, micro-, meso-, macro-, mega-relief' such that forms of identical genetic origin could fall into different size categories and be represented by different symbols; thus it is also impossible to depict individual objects with high information content, such as erratic blocks, due to their small size. The result of this attempt at an 'exact representation' ignoring the heterogeneity of characteristics with regard to their values as indicators of genetic correlations is an irreversible loss of information. Klimaszewski (1988: 466 ff.) considers that only 13% of the symbols of the GMK 25 have geomorphological content: "the GMK 25 may be useful in planning and in other branches of the economy but they are not primarily detailed geomorphological maps"[7].

The attitude of projects like the GMK in principle reflects a quite general trend of indoctrination obliged to an idea – analogous with those of primitive people who relate the consumption of lynx-eyes to visual accuity – that by the imitation of exact methods the relevance of those disciplines could be acquired, which like Physics had originally developed them in accordance with the special structures of *their* field of research. This trend obtains an even paralysing influence when its advocates do not hesitate to use their official positions to dominate scientific discussion, be they referees, consultant members of commissions or of unions (Kuhle 1989a, b). Thus it follows that, for example, critical photographic documentation of new kinds of geomorphological phenomena is dismissed as unscientific[8], the associated verbal description and representation of their regional relationships as 'unnecessarily complicated reasoning' and considered superfluous and instead the stereotypic application of quantificational methods such as 'substratum analysis' is advocated.

The Use of the Syllogism and the Polymorphism of the Type

The foundation of such a judgement is a commonly used but false syllogism in which the 'objectivity' derived from a quantifying analysis is regarded as a sufficient criterion for the possibility of general extrapolation and thus its function as a premise for deduction in every other context is taken for granted (cf. Footnote 2). Quantitative methods however can always and only serve empiricism as a *post hoc confirmation* because "no measurement can give more certainty than the determination of what is measured: i.e. the categories to which the object or phenomenon belong, the variability of their contents and the definition of their boundaries" (Riedl 1987: 176). Thus quantitative results of analysis of glacigenic accumulations of the Scandinavian ice-sheet could only be developed (by Ussing and Madsen 1897; Raistrick 1929; Münnich 1936; Dreimanis 1939) when their genetic derivation had been explained within the framework of a comprehensive theory (by e.g. Esmark 1827; Bernardi 1832; Ramsay 1855; Dana 1863; Torell 1875). Therefore they did not contribute to the primary genetic identification but only served – in the way of an immanent argumentation – the detailed reconstruction of source areas, directions of movement, depositional conditions and the extensions of the former ice streams[9]). As methodology advanced, perhaps largely in terms of techniques of analysis, the character of these accumulations could be described more accurately but a compulsory canon of properties in terms of a clear cut quantification (to form general premises for deduction) could not be derived[16]). The polymorphism of morainic deposits puts a limit to the extrapolation of quantitative definitions: the present moraines of the Scandinavian glaciers may have quite different particle size distributions, orientation- and rounding-statistics from those of their Würm-glacial relatives and also within contemporaneous morainic deposits the process of mixing with glacifluvial material (Fig 5 and 15) (and especially in mountainous regions also with solifluction-, talus- and landslide material) has such a basic (historical) randomness that a "characteristic morainic 'habitus'" cannot be converted into normative-quantifying boundary values but is adequately defined by a combination of polymorphic typological characteristics (just as classical morphology has developed). In Fig 1 to 15 sections of moraines are presented (with convergent mudflow deposits in Fig 18 and 19) to provide an impression of the heterogeneity of the material. Basic characteristics are 1) a wide particle size spectrum from clay to very large blocks, 2) the polymict intermixture of the material (no sorting or stratification) and 3) the juxtaposition of angular, edge-rounded and well-rounded fractions – everything varying within the widest statistical confidence bands. Additional confirmatory indicators, such as a high degree of compaction (leading to the formation of earth-pyramids Fig 2), depositional configuration, scratched and facetted boulders, orientation of long axes transverse or parallel to the direction of transport (in case of end- or lateral-moraines, respectively, depend on transport distance and petrography of the material (Fig 3, 4), topographic setting as well as the nature and extent of post-glacial reworking (cf. Fig 9, 11). Evidence for a glaciation however attains certainty not primarily from the pure presence of material typical of moraines but first of all from its spatial interdependence with other glaciogenic forms such as striations,

Fig 1 Exposure of late glacial lateral moraine at 2850 m asl in the Thulo Khola (S slope of Dhaulagiri, Central Himalayas). Typical mountain moraine with considerable variation in the distance over which the components have been transported; blocks reaching considerable sizes, angular, edge-rounded and facetted 'swim' isolated from each other in a matrix which is here rich in limestone. A differentation from mud-flow-diamictite can be inferred from its structureless and dense compaction as to be seen in the original depositional complex (cf Fig 18 and 19). The particle size histograms, and all other laboratory analyses, provide no differentation or even slight separation amongst mudflows or even between glaci-fluvial sediments from the same catchment area. A visual inspection in situ provides a more certain interpretation (cf Fig 20 and 23). Photo: M. Kuhle

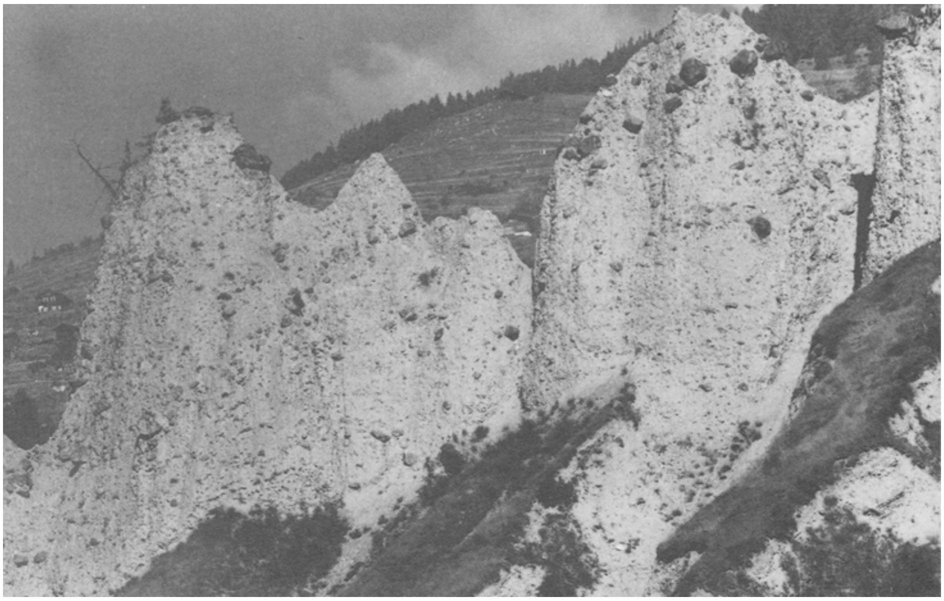


Fig 2
Late glacial Alpine ground and lateral moraine (Val d'Hérens, Valais). This is interpreted as strongly compacted and thus free-standing diamictite rich in fines forming earth-pyramids – here even without capping blocks. Mudflow sediments are on the contrary insufficiently compacted to allow the formation of earth-pyramids. As Fig 1 shows, the macroscopic overall view, together with the topographic and morphological relationships, facilitates the distinction between forms which are possibly convergent. Photo: M. Kuhle

erratic boulders, tongue basin deposits and glacifluvial outwash within the topographical situation. It was Albrecht Penck (1901–5) who worked out from such examples the 'system of glacial forms' and especially the 'glacial sequence' (= glacial basin – end moraine – transitional cone – outwash field) and thus raised Quaternary studies to the rank of a science (Schäfer 1981: 272). In spite of later changes and extensions of the scheme these geomorphological-stratigraphic methods have so far remained valid[10]. Thus if quantitative methods, which attain their value as evidence only within a context derived from typological argumentation, are now proclaimed and demanded as primary source of proof, geomorphological reasoning adapts to a tautological vicious circle, detracting it from the process of cognition and thus questioning its scientific status. The difficulties of epistemology referred to result from the old 'problem of induction': "All swans are white. In Australia, it is said, there is a black swan. Can it be a swan?" (Riedl 1987: 102). Whether it be a matter of swans or moraines, the question is at which point the empirical bases may be regarded as sufficient for the formulation of syllogistic premises. Quantitative exactness requires reduced perspectives, since the possibility of enumeration is based upon a high degree of abstraction. If the parameters of such a method, however, are shown to be unsuitable for the differential diagnostic interpretation of morainic material extended combinations of characteristics, such as the configuration of the deposit (structure) or topographic relationships (position) must be brought in. As the complexity of the perspective increases, the possible application of quantitative ideas decreases due to the increasing polymorphism of the phenomena "which are repeated many times *but hardly ever in an identical* manner" (Riedl 1987: 28 ff.). The unequivocation of syllogistic logic suffers from empiricism a statistical relativisation, so if "A is only roughly the same as B and B is only rougly the same as C, then C in no way needs to be the

Fig 3 These recent superficial moraines on the outlet glacier tongue of the Njordfjelletbreen, (●, Dicksonland, West Svalbard) and their associated end moraines (foreground ■) consist of angular detritus of lower Permian Spirifera limestone (↓↓) poor in fine material. The inherited characteristics of the morainic material as the result of the nature of the country rock and its weathering structure make it exactly comparable with the adjacent slope detritus (▼). Here again no sedimentological laboratory analyses provide a conclusive result. The reason for the very unusually homogenous particle size and arrangement of these moraines is however quite clear from examination of their relationships to the bed rock and the topographical setting. Photo: M. Kuhle

Fig 4
Very thick coarsely blocky surface moraine on a wall-foot glacier in the Aconcagua group (4200 m asl, Mendoza Andes 32° 30' S). Even the block fraction of this material is sharply angular; it is derived from andesitic vulcanites by rock falls and stone chutes and transported by avalanches down the steep back wall of this tributary glacier. In spite of its being transported by glacier over a distance of several kilometres it has taken up little of the character of a 'typical moraine'. Yet its working by overturning is intense; the blocks of the surface moraine falling frequently into opening transverse crevasses (× ×) and the pelitic substrate is continually removed by meltwater. If it were not clearly in contact with the ice a sediment like this could easily be misunderstood as purely derived from rock falls. Photo: M. Kuhle

same as A" (ibid). The truth content of typological reasoning thus necessarily depends on the breadth of its inductive basis i.e. the number of relevant characters and cases included as well as the empirically confirmed predictions and therefor on the level of probability attainable, in the same way as the natural laws of physics gain their certainty not from the immanent logic of their axiom system but from their empirically confirmed predictions[2)].

If the reality of typological concepts is related directly to their probability content its recognition must depend on the possibility of its inductive basis having an intersubjective transparency. The derivation of typological units constructed from fields of similarity based on the registration of analogies is however an effect of gestalt perception and rests on subconscious, reasoning functions of our physiological make up (cf. Lorenz 1959; Köhler 1971; Riedl 1981). Kepler already suggested that "similarity and analogy are the guiding principles of investigation" and Maxwell "developed these conciously to a well explained method of physics" (Mach 1926: 220–231); Lorenz (1974) showed them to be the source of scientific knowledge. The actual scientific proof i.e.

Fig 5 Exposure of lateral moraine (■) deposited in the trough between the marginal moraine and the valley wall covered with lateral sandr sediments (●) some decametres thick. These are lateral late- and neoglacial sediments some 2 km from the present terminus of the 25 km long K2 glacier (Karakorum N slope 36° N). The particle size histograms of these either pure glacigenetic or pure glacifluvial deposits composed of phyllites, gneises and granites are identical. Only analyses of orientation and sorting allow the very different methods of transport (ice and water) of these deposits to be recognised. The juxtaposition found here clearly shows the glacigenesis in the sense of a necessary combination of processes. Photo: M. Kuhle

Fig 6 Interior slope of the terminal moraines of the high-glacial stage in the Tamur valley, Kangchendzönga S slope (890 m asl near the settlement of Thumma, E Himalaya). Although the substrate has been carried here for over 60 km through a gorge like trough valley, the matrix is extraordinarily sparse ie it is dominated by sand and even gravel provided by the prevailing granite detritus derived from the local geological conditions; the normally typical clay dominated ground mass is missing. Optically the packing provided by the dominant psammite seems rather loose (though it is not) and, together with the strikingly angular large block components, seems to correspond almost completely to the characteristics of a mudflow sediment. The unequivocal morphological sequence of a glacier tongue basin formed by these wall-like deposits, the adjacent glacial polishing up valley and the associated outwash accumulations down are the firmest proof of their morainic character. Photo: M. Kuhle

the analysing search for the causal nexus of a similarity is in physics easily assured by the description of experimental arrangements and the possibility of logico-mathematical formulisation. If however the basis of induction (as in biological systematics or geomorphology) is provided by the summation of countless single observations (field study) of irreducibly polymorphic character, it can only be presented in the form of exemplary descriptions and it thus follows that the obviousness of its empirical basis remains necessarily less[11)] The demonstration of probability content thus appears as the basic problem of typological reasoning. In biology, for which the reality of the species as a type for the basis of taxonomy (and therfor for the theory of heredity based upon it) is of equally vital interest as in geomorphology[12)], the introduction of information theory (by Riedl in 1975) shows the way forward. The method is now briefly explained to demonstrate afterwards its application in the field of geomorphological investigation.

The Probability of Events

The basis for the calculation of the probability of events is the relationship between entropy, negentropy, information and order (the treatment follows that of Riedl 1975: 20–74). According to Boltzmann's fundamental postulate in thermodynamics in which the entropy S of a particle system is proportional to the logarithm of the thermodynamic probability W (based on Boltzmann statistics) of the respective microstate (the occupancy of the phase space cells).

$$S = k \ln W \tag{1}$$

where k is the Boltzmann constant ($= 1{,}380662 \cdot 10^{-23}$ $J \cdot K^{-1}$). The entropy (S) is a maximum for the most probable (i.e. random) distribution of particles in the phase space (thermodynamic equilibrium); for $W = 1$ i.e. complete fixation of the particle positions entropy is zero ($S = \ln 1 = 0$). In 1894 Boltzmann already recognised that the entropy concept provided an explicit measure of disorder and lack of information. Seizing on this idea Schrödinger (1944, 1951) transformed the Boltzmann equation to

$$-S = k \ln (1/W) \tag{2}$$

where negentropy ($-$ S) is a direct measure of order, organisation, segregation and information. In 1956 Brillouin accepted this definition and thereafter the majority of those practising biophysics and cybernetics. Information theory, founded by Wiener (1948) and Shannon and Weaver (1949) used on the contrary the original form of the entropy statement (1) and thus equates entropy, chaos, random mixing and disorder with information. This conflict in the idea of information is only apparent as the information content of an event reflects only the probability of its occurrence. It is simply a matter of context whether this probability must be interpreted as a realisation of randomness (themodynamics) or of determinism (biology) – the sum, however, of the informa-

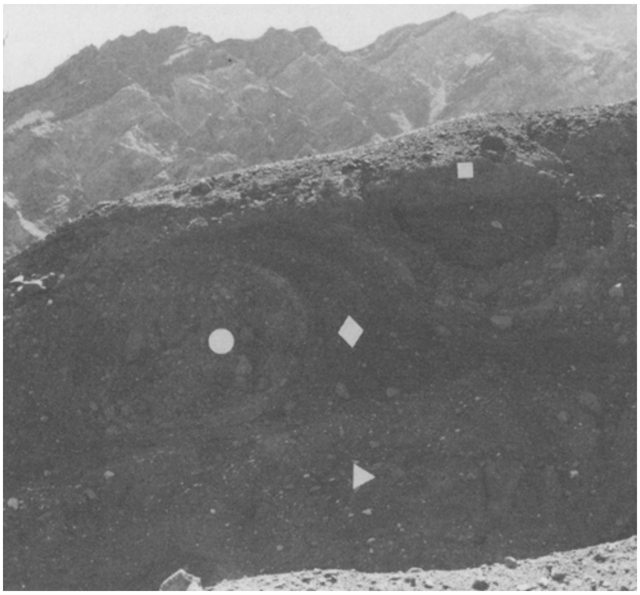


Fig 7 Neoglacial end moraine of the Horcones Inferior glacier, E slope of Aconcagua (Andes 32° 30' S 3700 m asl). The moraines deposited in the former glacier tongue area are transitional between former lateral and end moraines and besides have the character of a strongly disturbed ground moraine (▶). The complex structure exposed in the centre is a combination of pseudomorphotic texture (●) (typical of those substitute moraines formed by internal morainic detritus taking up the tongue-like cast of the thawed glacier ice) and of push moraine with down valley vergence (◆). This location is discordantly covered by a metre thickness of ablation moraine forming the uppermost layer (■). It is that with the greatest volume of voids ie the slowly down-thawing surface moraine of this very debris rich avalanche-fed ice stream has undergone no kind of compaction and the substrate of fines has been syngenetically washed away by meltwater, similar to grèzes-litées dynamiques. No laboratory method provides a comparable insight and no interpretative analysic can replace the qualitative field observations. Photo: M. Kuhle

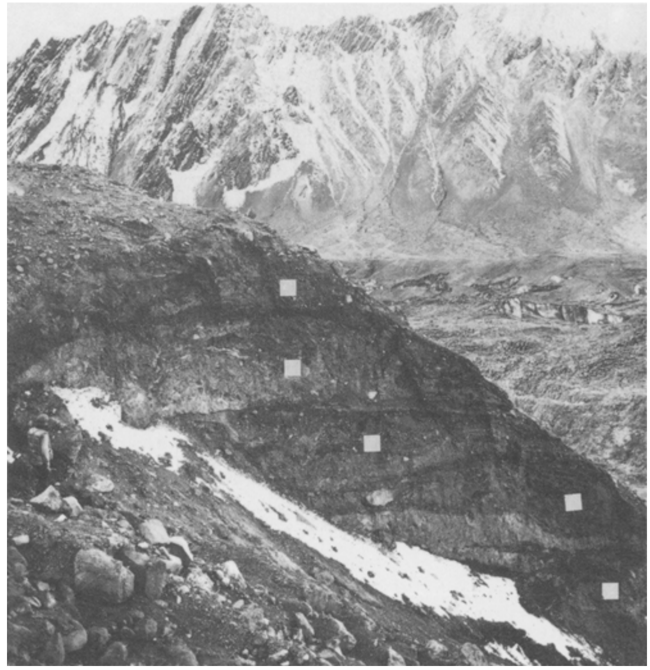


Fig 8 Subrecent banked lateral moraine of the Horcones Inferior glacier (Aconcagua E slope, Andes 32° 30' S 4000 m asl). In the background, covered with surface moraine, is the present glacier. The stratification or banking (■■■■) is built up by successive debris deposition upon older layers sometimes up to 1 m thick – an example of a glacigenetic diamictite, which is also layered. Photo: M. Kuhle

tion content (I_D) and the determination content (D) of a defined system, i.e. the general information content, remains constant

$$I_D + D = \text{constant} \tag{3}$$

In the sense of information theory the information content (I) of an event (x) is measured in the unit 'bit' and is equal to the $\log_2$ of the reciprocal of its probability (P)

$$I_x = \log_2 1/P \tag{4}$$

In the simplest case, as in the tossing of a coin, the probability (P) that the next event will be tails (x) is $P_x = 1/2$, the reciprocal is $1/P_x = 2$; with a binary choice between two alternatives $\log_2 2 = 1$ so that $I_x = 1$ bit. This is however only the case if the events heads/tails are quite undetermined i.e. random. If the system contains a deterministic mechanism (favouring e.g. tails) then $P_x = 1$ and the information content $I_x = \log_2 1 = 0$. From the point of view of the probability of order the disappearance of indeterminateness results in a maximisation of the determination content (D) i.e. bit_I becomes bit_D (formula 3). Thus, according to Riedl, two different probabilities (P) must be considered; the probability of a chance or indeterminate event (P_I) and the probability of a determinate one (P_D) where each is a reciprocal of the other.

The degree of probability with which a determinative law is present (P_g) can be expressed as

$$P_g = P_D/(P_D + P_I) \tag{5}$$

where $P_g = 1$ gives a maximum probability and $P_g = 0$ is a maximum improbability of a determinative law. In the discovery of lawlikeness the basic role of experience is thus made clear by these formulae; the hypothesis that in a series of coin tossings 'tails' is favoured deterministically gains little certainty with the first throw since $P_g = P_D/(P_D + P_I) = 1/(1 + 0.5) = 1/1.5 = 0.66$. But with the second, fifth and tenth throws the probability of a random explanation steadily decreases to 1/4, 1/32, 1/1024 (i.e. as $1/2^2$, $1/2^5$, $1/2^{10}$) and thus that of a determinism increases from $1/(1 + 0.5^2)$ to $1/(1 + 0.5^5)$ and $1/(1 + 0.5^{10})$ i.e. from $P_g = 0.8$ to 0.97 and 0.999. By the hundredth repetition the probability of a determinative law attains certainty with $P_g = 1/(1 + 0.5^{100}) = 1/(1 + 7.9 \cdot 10^{-31})$. The probability of lawlikeness

Fig 9
Löss-covered complex of terminal moraines (see also Fig 10) in the N foreland of the Kuen Lun between 1900 m and 2700 m in altitude (taken from 2700 m towards the SE). In the background are the mountains of the N border of Tibet, draped with löss dust and still glaciated today, through which these foreland glaciers have flowed. The present valleys were filled with glaciers during the last glaciation: as they melted down an away and autochthonously fed erosion and V-shaped valley formation occurred which looks at first sight like the badland formation found in suitably weak rocks (eg Neogene sandstones and comparable sediments in Arizona). The thickness of these features, several hundreds of metres, is comparable with that of the glacigenic deposits in the foreland of the Aosta valley (S slopes of the Alps). Photo: M. Kuhle

(P_g) with respect to the number of occurrences (P_{ga}) may thus be written

$$P_{ga} = P_G^a/(P_G^a + P_I^a) \tag{6}$$

in which (a) is the number of occurrences of the same combination of events. If the existence of a determinism is approved by the continuous outcome of a series of occurrences this formula simplifies to $P_{ga} = 1/(1 + P_I^a)$. The function of re-occurrence (redundancy) for the recognition and confirmation of non-random events is however directly related to the richness in characteristics of the underlying determinative law. The more complex the combination of characters in the occurrence the more unlikely is a random explanation even with low values of (a). For a system with five independent binary distinctions e.g. five coins all with definite positions (e.g. all tails upwards) the random probability that such a special configuration may occur at one throw is 1/32 or 2^{-5} i.e. the same value as for a system of one coin after five repeated throws (see above). A system of ten coins shows a random probability of $2^{-10} = 1/1024$. The same result is obtained if a five coin combination is thrown twice (a = 2). The random probability that in the two cases all tails lie upwards is $2^{-5 \cdot a} = 2^{-10} = 1/1024$.

It is thus clear that the determinative content (D) of a series of occurrences is proportional to both the law content (G) and the redundancy (i.e. repeated trials (a)) and therefor

$$D = G \cdot a \tag{7}$$

The probability – and this is the essence of the inductive method – of a lawlike determinism thus potentially increases with each identifiable character and each identical re-occurrence.

However, if we have now acquired a quantitative measure for the probability of an hypothesis of determinism the core problem for its application is the qualitative definition of what may be counted as an 'identical' re-occurrence. For the calculation of $G \cdot a$ and therefor of (P_{ga}) the foundation is the acceptance of an identical replication (a) of a defined series (G = all five coins showing tails). Though in the case of coin throwing this is easily specified, on a higher integration level the question of the identity of character combinations whose elements form the nodes of a many-dimensional web of relationships and thus necessarily are of a polymorphic phenomenology is a very different matter. Indeed, if the perception of a re-occurrence is based upon similarity, the fact of such similarity still is not proof of the identity of the underlying deterministic cause.

The Semantics of Similarity

It is well known that the apparent similarity of forms of sharks and dolphins is not the result of their identical descent from the same ancestors: sharks (Selachii) have descended from primitive cartilagenous fishes (Chondrichthyes) whilst whales (Cetacea) in relationship with pigs (Suinae) can be traced back to primitive hoofed mammals (Condylarthra). In the same way the similarity between the jaw joint of the cartilagenous fishes and that of mammals is purely functional. But there is identity between the elements of the primary jaw joint (articulare and quadratum) of the cartilagenous fishes and the auditory bones (hammer and anvil) which transmit sound in the ears of mammals. The different meanings of similarity in biology are conveyed by the ideas homologue and analogue. Those structural similarities are analogous which, though deriving from different origins, are functionally adapted to environmental conditions which by chance have been equal (so-called convergence). Structural similarities are homologous if they derive from identical origins i.e. they may be explained

Fig 10 Glacigenetic diamictite in the lowermost strata of the last glacial foreland moraines on the S edge of the Tarim basin at 2000 m altitude (cf Fig 9). Here the significant fraction of fine material is related to the grinding power of considerable ice thickness and far transport (up to more than 100 km) into the foreland (with no contribution of coarse debris from valley sides). This is especially noteworthy because the aridity of the glacial period was more effective in the formation of coarser moraines (cf Fig 11 and Fig 12). Inclusion and intercalation of glaci-limnal deposits (×××) betray the proximity of the sedimentation to the edges of the glacier. Push phenomena occur as sickle- or mussel-like break off on the outcrop surface (↓↓). Photo: M. Kuhle

Fig 11 Orographic right lateral moraine (●) in Tangdung Khola (2400 m asl; Annapurna Himalaya, W slope of Nilgiri). The accumulation has a classical terraced form so that it could be taken for a fluvial deposit. The outcrop (● see Fig 12) shows in fact a purely glacigenetic diamictite. Photo: M. Kuhle

as having a common descent but whose differences derive from later divergence in their lines of development. In geomorphology there is a similar differentiation between 'genetic formation' and 'convergence formation' There is the well known misleading similarity of the polygonal dessication crack network and that of ice-wedge polygons which is also found as a general pattern in periglacial soil structures as well as in cooled basaltic sheets, the cells of the beehive and the Bérnard cell circulation of heated fluids. The analogy lies here in the physico-geometrical necessity by which complete subdivision of a surface without gaps inevitably results in a polygonal pattern. In the same way the similarity of avalanche cones, talus cones, alluvial cones and estuarine deltas owes its character to the random alterations of the direction of the transport processes which underlie them, arranged as a 'bifurcation cascade'. Frequent repetition within definite limits results for example in the symmetrical form of the cone sheet or fan (cf. Fig 16 and 17). The same 'fractal structure' which may be described by the Mandelbrot algorithm ('little apple man', 'Apfelmännchen') is also found in the ramification of lightning strokes, tree crowns and in the circulatory vessels of the blood. It is clear that convergent similarity, which here dominates the genetic (by identity of process) is not to be included in the calculation of character coincidences. For example particle size analyses, converting morainic accumulations, into quantifications showing greater differences between each other than to those produced by other genetic processes, such as outwash gravels (Fig 20) or mudflow (fanglomerate) deposits (Fig 18, 19) may not be taken for homologous characters. Combinations of characteristics from which genetic conclusions may be drawn must be referred back to an unequivocal relationship to a common dynamical process; thus the series 'trough valley – trimline – roches moutonnées – tongue basin with ablation moraines – terminal moraine – sandr outwash' can only be subsumed under the genesis 'glaciation'.

The differentiation between homologous and analogous similarities is thus equally applicable to biology and geomorphology[13]. The criteria by which homo-

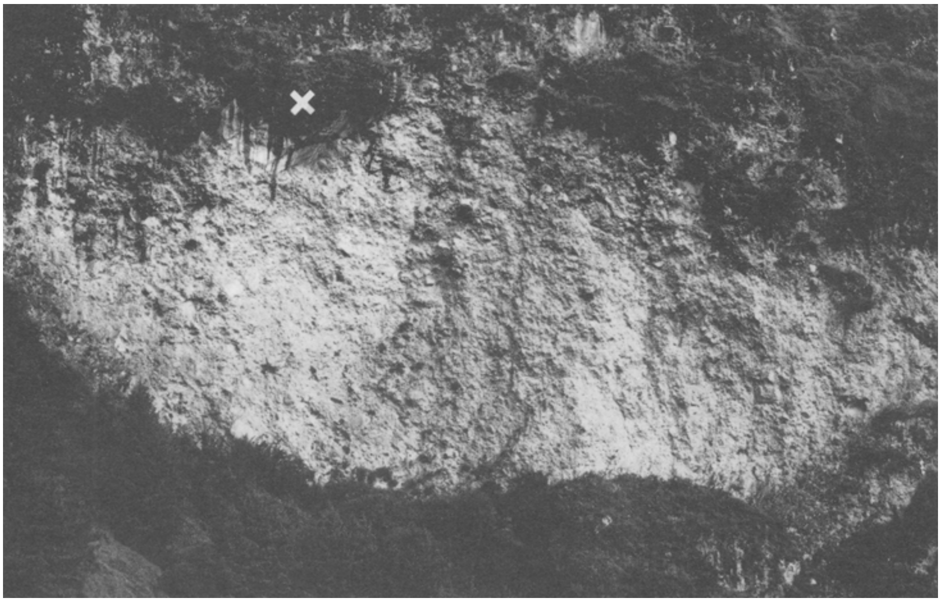
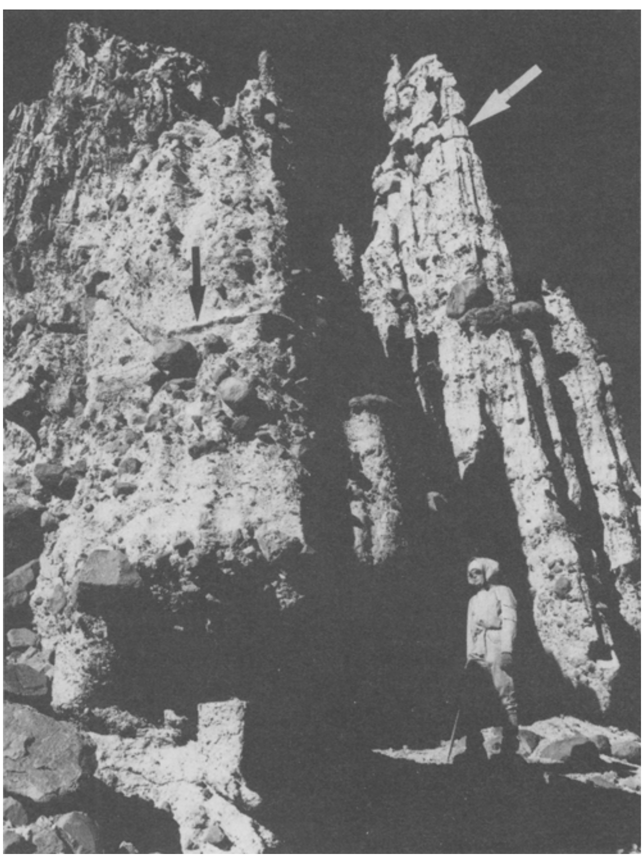


Fig 12
A late glacial lateral morainic material (locality Fig 11 ●) with a strongly mixed particle size spectrum and a considerable fraction of compacted fine material in which isolated edge-rounded and angular blocks (×) (up to the size of a house) are embedded. Such a high proportion of fines is typical of fast flowing humid (monsoonal) glaciers with rapid mass turnover.
Photo: M. Kuhle

Fig 13 Median moraine deposits of a high-glacial ice-stream network in the subtropical Andes between 32° and 33° S (E of Co. Amegino and Co. Aconcagua; 4750 m asl, 750 m above the present valley floor of the Quebrada Relinchos). Many of the coarse, rounded or facetted vulcanite blocks cap earth-pyramids. They bear syn- and post-genetic iron manganese crusts. Although the substrate is chaotic there is at the same time a coarse diagonal banking (↓↓) characteristic of lateral and medial moraines. Photo: M. Kuhle



logues may be determined in geomorphology may be taken over from those developed by Remane (1971: 30 f. quoted in Riedl 1975: 60) (i.e. 1–3 main criteria, 4–6 supplementary criteria) provided that the idea of 'species' is replaced by 'regionally independent occurrences of equal form elements'.

"*1 Positional criterion:* homology results from equal position in comparable systems of structures.

2 Structural criterion: similar structures can also without reference to equal position be considered as homologous if they agree in many special characteristics. Certainty increases with the degree of complication and correspondence of comparable structures.

3 Transition criterion: even dissimilar and differently located structures may be explained as homologous if transitional forms are found between them so that in consideration of two neighbouring forms conditions 1 and 2 are fulfilled. The transitional forms can be realised within the individual development of the structure or as true systematic ones.

4 General coincidence criterion: even simple structures can be explained as homologues if they occur in a large number of species close to each other.

5 Special coincidence criterion: the probability that simple structures are homologous increases if further similarities with the same distribution occur in closely similar species.

6 Negative coincidence criterion: the probability that characters are homologous decreases with the frequency with which they are met in species which are certainly not related" (convergence forms).

In order to determine characteristics that may be used in quantification according to these criteria (i.e. those referring to an identical dynamical process) upper and lower limits must be derived for them; 'frame and minimum homologues' (Riedl 1975: 64 f.). Such distinc-

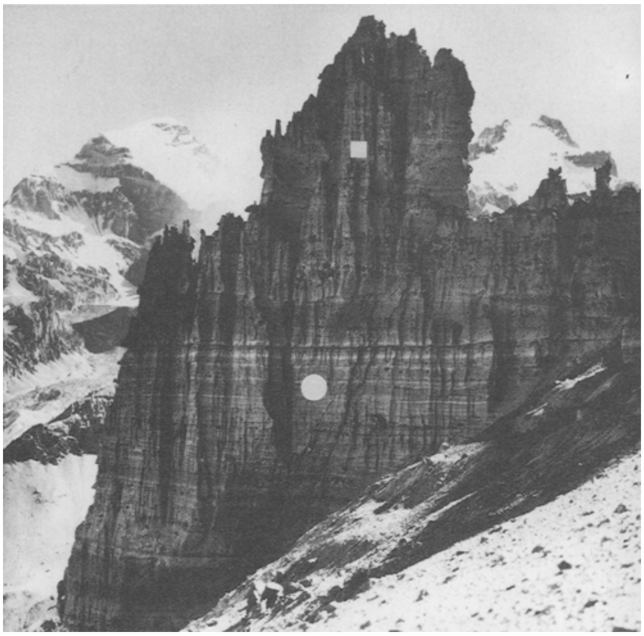


Fig 14 Glacigenetic marginal deposits in the subtropical Andes (locality see Fig 13; left in background the 7000 m high Co. Aconcagua, right the 5800 m high Co. Amegino). Although they are located at 4650 m altitude on the valley crest and 650 m above the floor (background below left), they are horizontally stratified glacier lake deposits (●; in part the medial moraine material appears to be intercalated with volcanic strata) the situation of which implies necessarily the former existence of a valley filling glacier against which they were laid. The upper parts are rich in large blocks and chaotic and thus clearly deposited directly by glacier ice (■). They denote a slowly rising ice level which finally reached the height of Fig 13. Photo: M. Kuhle

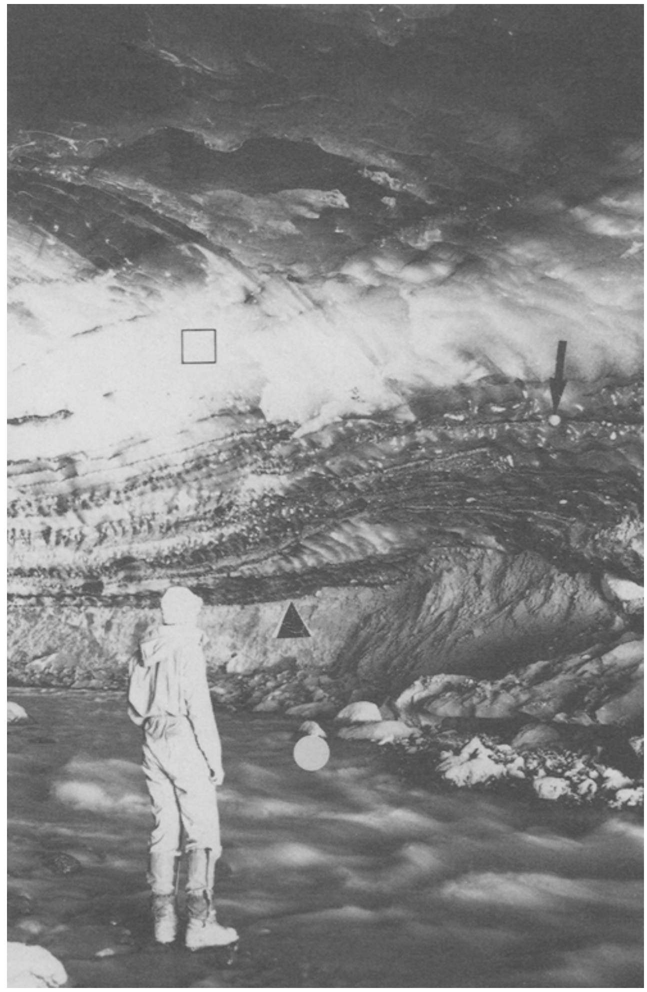


Fig 15 Present day deposition of ground moraine below the existing Plomo Glacier (Andes 33° S Co. Juncal Group 3600 m altitude). Under the burden of ice (□) the grinding is most intensive at the transition between ground moraine layer and the active glacier (▲). Pebbles sorted by meltwater (●) are already being incorporated subglacially. As the ice melts the ground moraine is covered by the outthawed inner (↓) and surface moraine (▲ cf Fig 4 and Fig 7). Photo: M. Kuhle

tion is due to the basic hierarchical arrangement of homologues in which each concept of homology reaches its full identity only with both the signature of its superior concept and from the representativeness of the lower order characters. The upper framing limit of homology, which in biology occurs in the individual as a representative of the species, is determined in geomorphology by such landform units within which the interdependent characters of a genetical form-type are completely represented. In glacial morphology for instance such units are given by the area of erosion and deposition of one individual glacier which are unequivocally determined by the relief setting (ice-sheds, valley sides, slope lines) and ice-marginal sediments. The lower boundary of the minimum homology is reached by the identical units of mass (homonoma) which are indeed countable but no longer distinguishable within the 'Type' by their position. Thus the 'trimline', the transitional zone between glacially polished rock elements and the unpolished rock surfaces, can be observed as a linear element frequently kilometres in extent along the flanks of the valley – perhaps divided into greater or lesser portions by tributary valleys or more recent processes of erosion. The single elements of the trimline attain their value as indicators only if integrated into one complex, within which they are interchangeable with one another and thus identical; they enter into the calculation as one lower minimum homologue (and similarly for glacial clasts, erratic blocks, roches moutonnées, components of fluvial gravels etc.). A further subdivision would enter the level of the even greater numbers of 'homonomic' crystalline components of the basic rock material and thus the genetic context of 'glacial formation' would be lost.

As in biology so in geomorphology "homologa . . . are countable and identifiable, hierarchically arranged individuals, bounded above by that total individuality, which we determine as identical individuals and below by the identical mass individuality of the elements they

Fig 16 Ice avalanche cone (■) on the Horcones Inferior glacier at the foot of the 2800 m high E wall of Aconcagua (Andes 32° S 4100 m to 4400 m asl). This conical form of ice avalanche debris is convergent in origin with a rock-debris cone (cf Fig 17) derived from rock fall channels or 'Murtobel' (mudchutes). Thus these cones are attached to large rock funnels in the back wall that have been eroded by ice avalanches. (↓↓). The detritus torn from the wall melts out at the cone edge building up the surface moraine of the glacier below the ELA. Photo: M. Kuhle

Fig 17 Mud flow and talus cone in the Quebrada Horcones (Aconcagua Group, Andes 32° 30' S 3900 m to 4500 m asl). The exposed angular and relatively matrix-poor coarse detritus shows a slight layering (cf Fig 18) and cannot be distinguished from a sparse montane glacier moraine without geomorphological analysis. Photo: M. Kuhle

are composed of" (Riedl 1975: 68). The methods described are applied in what follows to the real example of a new Type of glacial accumulation which is called 'Bortensander' (ice-marginal ramp = IMR) which was first described by the author in 1974 and has been able to be verified over sixteen years of field investigation as a central indicator of semi-arid piedmont glaciation.

The Inductive Material to Justify Type an Term 'Bortensander' (= Ice-marginal Ramps)

Ice-marginal ramps are ramp-like deposits formed under semi-arid conditions and extend, often for tens of kilometres, along the margins of piedmont glaciers. The proximal ice-contact slope stands like a morainic wall locally up to several hundred metres high above the now ice-free glacier tongue basin (Fig 22, 33, 34). Downstream of the highest point the morainic material is progressively covered by an increasing thickness of glacifluvial outwash-layers (Type A Fig 21) or (Type B) the morainic culmination is already covered with outwash the layers of which crop out towards the basin itself. With average slopes between 7° and 15° these increasingly sorted outwash deposits extend several kilometres, or even locally several tens of kilometres out into the foreland.

The combination of *two* dynamic processes (glacial/fluviatile) in the formation of *one* depositional complex in relation to the semi-arid climatic conditions which in themselves seem to counter-indicate glaciation has led to confusion, neglect and frequent misidentification of these forms. As the result, in spite of the evidence and conclusion of earlier scientific travellers (summarised in Kuhle 1988d), only recently has the evidence for the 2.4 million km^2 ice sheet glaciation of Tibet been demonstrated (Summaries in Kuhle 1987c, 1988a, b, c). The inductive material from which the definition of the 'Ice-marginal ramp' and its glaci-genetic interpretation is derived, is compounded of the co-existence of specific homologous characteristics (G) and of those independent repetitions (a) which accompanied their chronological recognition (a summarised, regionally extended description of ice-marginal ramps with their arrangement into widespread form complexes is to be found in Kuhle 1989c).

The Ice-marginal Ramps of Kuh-i-Jupar (29° 40'–30° 15' N, 56° 50'–57° 35' E)

Two well-defined glaciations during the Pleistocene can be demonstrated in the Kuh-i-Jupar, a mountain massif in SE Iran reaching 4000 m asl (Kuhle 1976). During the earlier one, glaciers up to 17 km long flowed into the foreland and combined to form ice lobes with a maximum width of 20 km. The glaciers of the later glaciation barely reached the valley outlets and remained

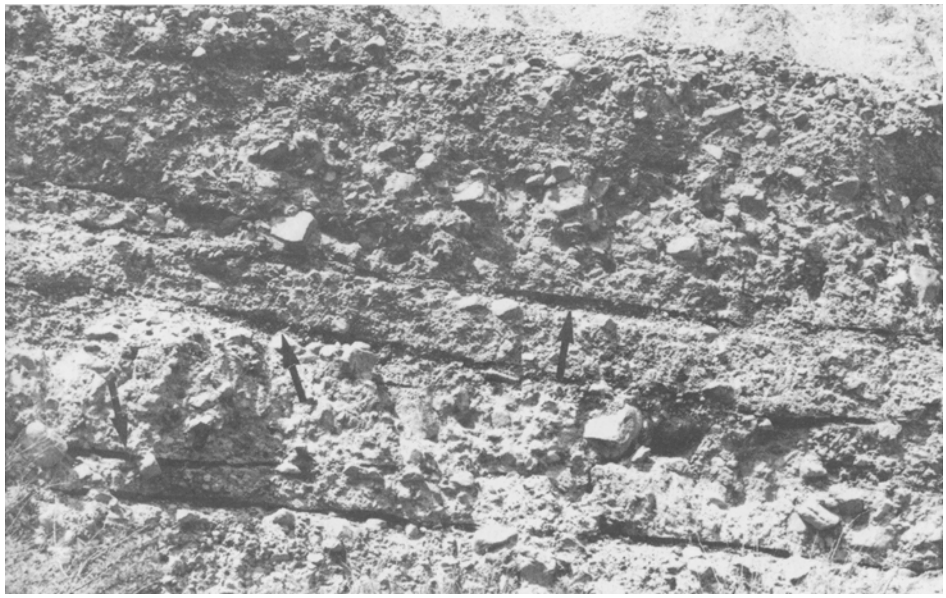


Fig 18
Mudflow sediment in the Yarkand valley (longitudinal valley between Aghil Mountains and Kuen Lun/ High Asia 37° N). Both morphometrically (a mixture of angular and rounded coarse blocks), and in terms of cumulative particle size as well as in the isolation of the blocks from each other by the ground mass mudflows show a convergence towards morainic diamictite (see also Fig 19); even a polymict juxtaposition of blocks may occur. Field study alone shows the mudflow character of the banking (↑↑) betrayed by the easily washed out layers. Photo: M. Kuhle

isolated from each other by rocky spurs. The outlines of the glacier tongue basins are marked by ice-marginal ramps (Fig 26). The long profile of the IMR uniformly begins with morainic material which (Fig 30) is characterised by

1) a complete spectrum of particle sizes from clay through silt and sand as far as block size material, the components of which reaching dimensions which are not consistent with fluvial transport (Fig 24). The material is chaotically arranged, sorting and layering are absent and there is at most a crude 'banking' of the polymict depositional components.

2) no type of shape predominates i.e. there are angular, edge rounded and round components.

3) the morainic depositional complex rises as a wall above its surroundings and thus forms the proximal stage of the ramp of the IMR (Fig 22).

4) in plan the pronounced morainic wall forming the boundary has a lobate or tongue-like configuration (cf. Fig 26; Kuhle 1989 Fig 9, 14).

5) Type A, Fig 21 has glaci-fluvial deposits attached beyond the highest part of the moraine with a successive horizontal transition from a glacigenic to a fluviatile depositional environment i.e. the characteristics of the morainic material give way to an increasingly fluvial one without an abrupt dividing line being distinguishable. This gives proof of a syngenetic relation of two processes arranged into a complex unit. In Type B the morainic wall is already overlaid with discordant glaci-fluvial deposits (Fig 23); the horizontal transition from morainic to fluviatile material in the deposits can be seen in exposures.

6) at increasing distance form the proximal limit of the IMR the characteristic fluviatile nature of the deposits is shown by its clear sorting and and stratification. The fluviatile process acts primarily by a reduction of the particle size spectrum so that the coarse blocks of the proximal area give way to the finer material of the outwash. Towards the marginal areas of the alluvial fan the reduced power of transport leaves the coarse fraction behind so that the spectrum has a tendency to displace from coarse to fine towards the periphery. The seasonal variation of the amount of discharge and the migration

Fig 19 Mudflow channel a few days old at 1700 m altitude in the central Himalayas (Thak Khola, Daulaghiri-Himal) in which hut-sized granite blocks were moved in a fine loamy ground mass. It was not triggered by a spring snow melt or from perennial snow patches in the upper catchment area but by the water saturation of the sloping soil layers due to intense summer monsoon rainfall. This also produced a deposit convergent towards a glacial diamictite 2000 m below the forest boundary by warm moist mass movement. Photo: M. Kuhle

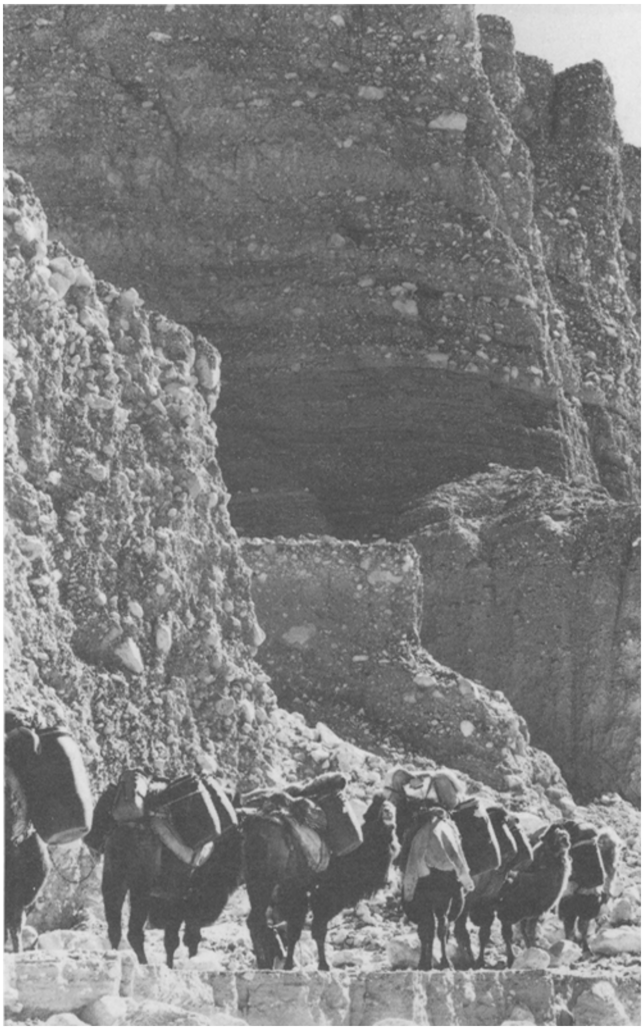


Fig 20 Glacifluvial deposits of a thick outwash (sandr) cone in the Shaksgam valley (longitudinal valley between the Aghil mountains in the N and the Karakorum main range in the S; 36° 30' N, 4100 m asl). These ill-sorted but clearly washed gravels and blocks are very heterogenous in their grain size distribution up to the gravel fraction, so that in some parts they seem to correspond more to a glacial diamictite and mudflow deposits than to pure fluvial sediments. Only macroscopic field observation provides a definite interpretation as outwash material. Photo: M. Kuhle

of the outflow channels over the depositional surface produces a permanent shifting of the zones of equal particle size fractions. The result is a well defined sorting of particle size so that in section there is an alternation of layers of fine and coarse material. Mixing up those glacifluvial layers the cumulative particle size curves of the fraction silt to sand thus may show the same shape as that of the present morainic material from which they have been sorted into time-differentiated layers by water action. Visually however the difference between chaotic glacigenic material and sorted outwash layers is quite clear (compare Fig 24 with Fig 25; Fig 23).

7) in contrast to undifferentiated roundness statistics of the morainic material the outwash deposits are dominated by edge rounded and rounded to well rounded components with an orientation of long axes transverse to the direction of transport.

8) the internal layering of the outwash shows older steeper layers capped discordantly with increasingly less sloping overlying younger deposits. This denotes a multiphase long period build up of accumulated material which is explained by the inherent marginal stability of

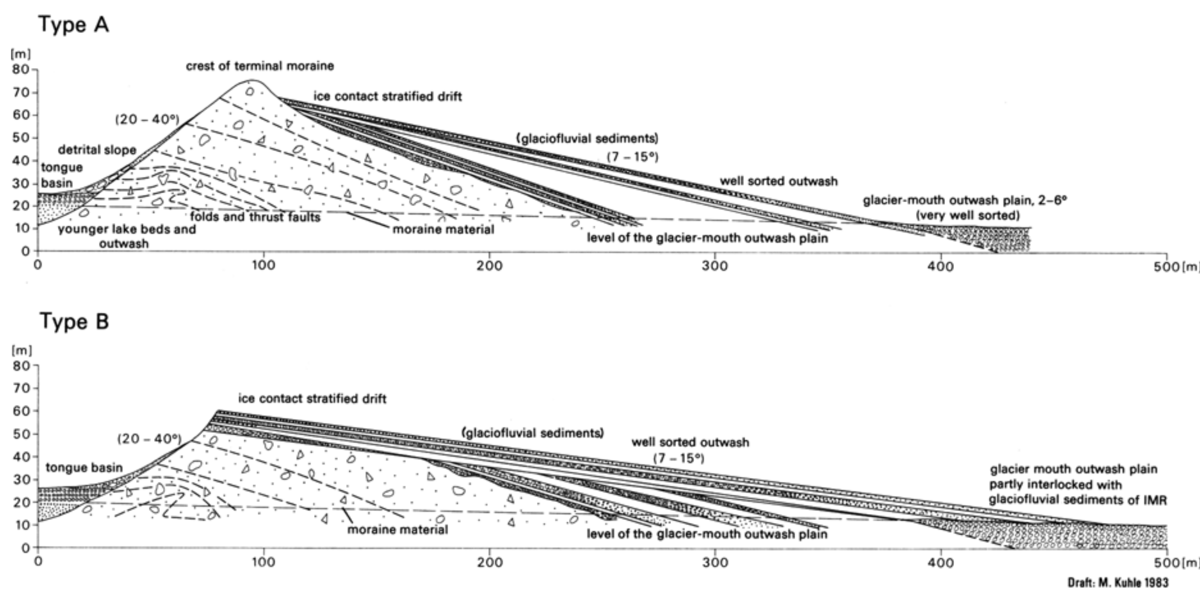


Fig 21 Ice Marginal Ramps (cross profile)

Fig 22 Glacier tongue basin surrounded by ice-marginal ramps (▼) in the N foreland of the Kuh-i-Jupar (cf Fig 26; 4100 m high massif in the SE Zagros mountains of Iran, 29° N). To the orographic right-hand mountain spur there is attached an arcuate lateral moraine (×). The accumulated material in the foreland begins at 2200 m asl (foreground) and extends down to 1700 m in the basin of Kerman in the background. The ice-marginal ramps (▼) occur as transitional cones (Fig 21 Type B; cf Fig 33 and Fig 34) partly superposing the frontal moraines (Fig 24) and extend with a slope around 11° down into the foreland. Here they disappear below the gently sloping outwash fans (Fig 25). Seen from there the ridges of the ice-marginal ramps (▼) (cut and separated from each other by incised small ravines arranged at right angles to the former ice edge) extend up to the mountains and cut out with a precipitous exposure at the edge of the glacier tongue basin (cf Fig 33 and Fig 34). Previously they were misunderstood as the remains of gravel fans eroded into glacial-tongue-like features. However in this case there was no explanation of their change of material from glacial diamictite to sorted outwash plain sediments, nor of their steep surface gradient implying a former considerable thickness of several hundreds of metres. The hills in the middle ground (↓) lie at 1800 m – 1900 m and are the remains of the ice-marginal ramps of the foreland glaciation during the Riss period (see Fig 23 and 26). Photo: M. Kuhle

Fig 23
The head of an ice-marginal ramp produced by the former (Riss) glaciation in the N foreland of the Kuh-i-Jupar (1950 m asl in the SE Zagros; locality see Fig 22 ↓). This is an example of Type B (see Fig 21); below is the glacigenetic diamictite with polymict blocks (of limestone and conglomerate) which belong to the frontal moraine complex (■) visible. They lie upon Neogene sandstone (×) and above them are exposed transitional glacifluvial outwash materials dipping at 7° to 15° (●). They are well sorted and lack very large blocks. Photo: M. Kuhle

Fig 24 Section of the front slope of an ice-marginal ramp (younger glaciation – Würm) in the N foreland of the Kuh-i-Jupar (2200 m asl, SE Zagros S of Kerman; locality see Fig 22). This shows polymict coarse morainic blocks (limestone – light and Kerman conglomerate-dark) isolated from each other in a relatively sparse groundmass. As the particle size decreases the components become more and more angular; the blocks are well rounded. The proportion of large blocks decreases up to the ridge of the moraine. A 70 cm ice pick provides a scale of size. Photo: M. Kuhle

Fig 25 An area of glacier outlet outwash material (sandr cone sediments) of Würm glacial age in the N foreland of the Kuh-i-Jupar (2200 m asl; locality see Fig 22 central between ▼ and ×). This is strikingly better sorted than the more steeply deposited glacifluvial ice-marginal ramp material. By comparison there are within it fewer large blocks (of limestone). The spectrum of finer particles cannot however be distinguished from that of the nearby moraine or the ice-marginal ramp. Photo: M. Kuhle

the piedmont ice lobes in terms of significant volume and low velocity of movement.

9) the extraordinary steepness of the outwash material (7° to 15° with a mean of 12°) contrasts with that of the present gravel floors of the montane valleys (2° to 6°). This large dip of the outwash surfaces which in case of the earlier glaciation even begins at a 10 km distance from the mountain foot cannot be explained in terms of present relief since to make this angle of 7° to 15° possible an excessively large body of gravel reaching up into the area of the summit levels would be necessary to bridge over the distance to the catchment area. Actually the advance of the former glacier bodies had created an 'artificial' rise of the surface level in the foreland. The meltwater discharge from the glacier surfaces over the culminations of the terminal moraines led to the deposition of the steep outwash.

10) at right angles to the course of the end moraine ridges the IMR are dissected by small valleys running roughly parallel to each other (Fig 22). These begin abruptly without the widening of a catchment area and are incised into the upper edge of the IMR. This, and their occasional expansion to broad wash channels accompanied by the climatically sparse vegetation cover, shows that these are fossil forms which today are only developing in traditional ways. They may be explained by the increased quantities of meltwater of the glacial retreat phase.

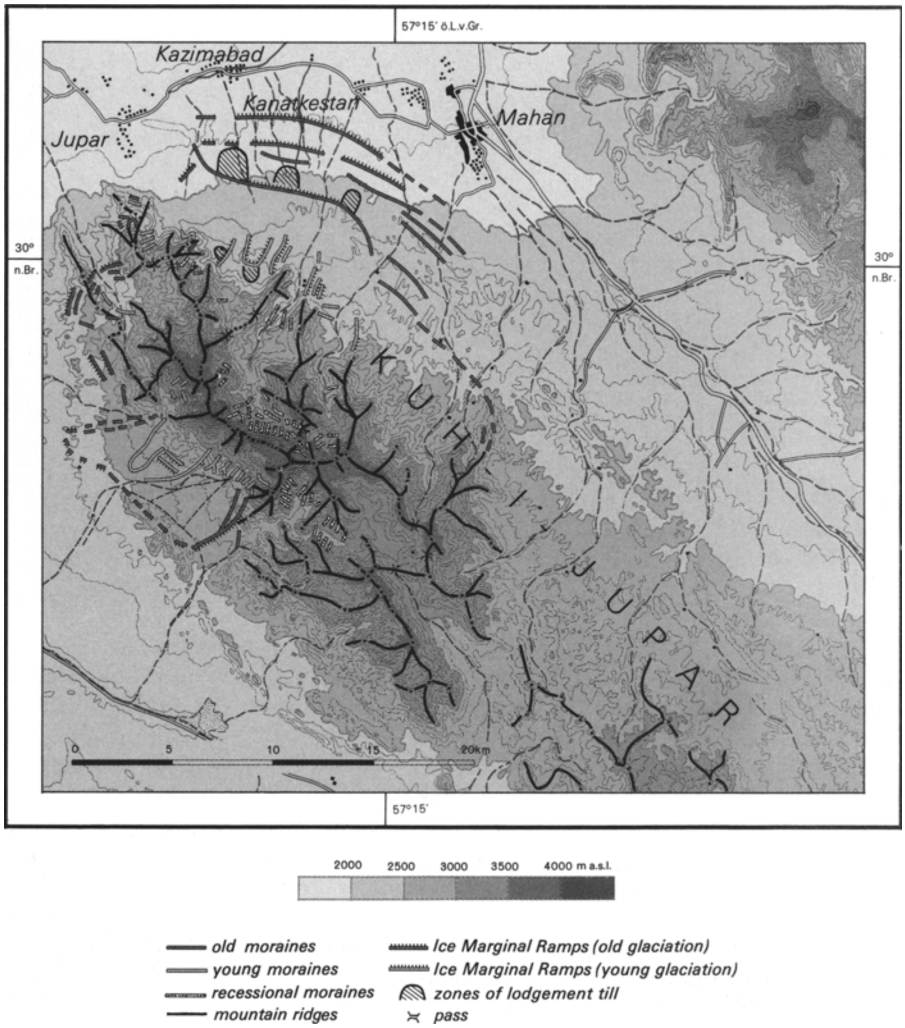


Fig 26
Moraines and ice-marginal ramps of the Würm and Riss glaciations in the Kuh-i-Jupar (SE Zagros, S of Kerman, Iran).

11) the topographical arrangement of the (glacier) tongue basins indicated by the IMR is correlated in a typical glacigenetic manner with the altitude of the related ice catchment areas and their exposure (Fig 26). The higher the related catchment area (mean height of the surrounding ridge of the basin) the lower is the position reached by the corresponding glacier tongue basin. If the method for the calculation of former equilibrium line altitudes (ELA) (developed by v. Höfer, 1879, on Alpine glaciers; the ELA lies according to him about half way in height between the mean elevation of the catchment and the lowest level of the glacier lobes) is applied here a uniform level of the ELA results inspite of the non-uniform terminal levels of the glacial phase in question (e.g. for the younger glaciation of the north slope of the Kuh-i-Jupar the ELA values found lie at 2975 m, 2880 m and 2975 m asl; Kuhle 1976: 195). Moreover, the slopes of the same massif exposed to the south, with their greater exposure to radiation, show less glacierisation i.e. a greater height of comparable ELA levels even where, as in the Kuh-i-Jupar, the winds bringing precipitation come from the SW (on the SW and S slopes the ELA values of the younger glaciation are between 3150 m and 3220 m). The special topographical dependence of the IMR arrangement makes their glacigenetic context clear.

By analogy with the Alpine model of glacial morphology the existence of glacial erosion and accumulation features in the related catchment areas in the mountains is to be expected. In the Kuh-i-Jupar can be found.

12) trimlines and transfluence passes which can be detected as large scale phenomena (documentation in Kuhle 1976: 127–197; Fig 70, 85, 133, 151);

13) erratic blocks which, since they lie on different country rock, indicate areas of origin several kilometres away on the opposing valley flanks (Fig 29; Kuhle 1976: 132) as well as remains of lateral moraines high above the valley floors (ibid: Fig 147, 150 and 43);

14) roches moutonnées (ibid: Fig 72) and polished valley bottoms (Fig 28)

15) glacially polished rock surfaces still retaining striations (Fig 27). The valley glaciation reconstructed thus, with ice thicknesses of 500–550 m at the ice

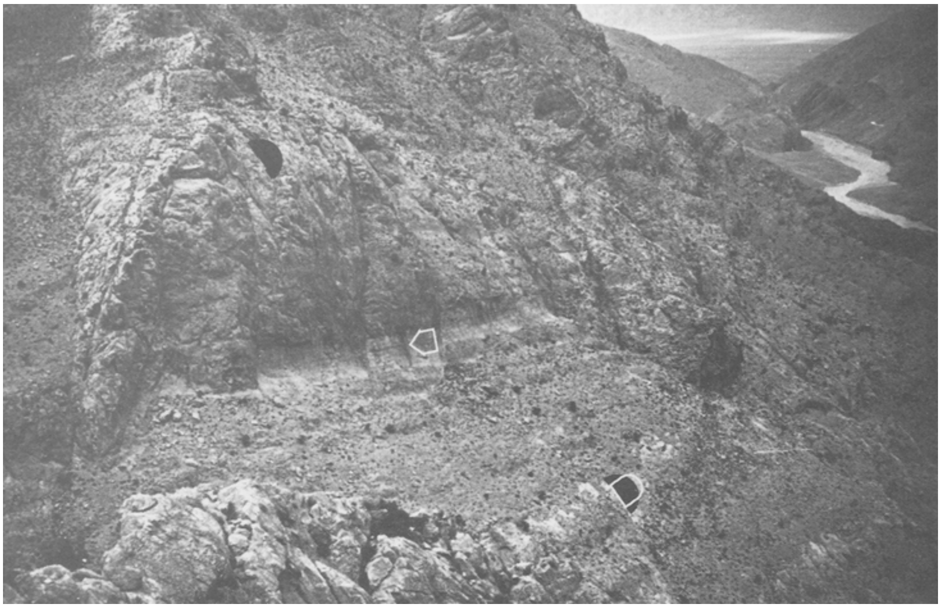


Fig 27
Well-preserved glacial striations in massive Cretaceous limestone at 2800 m asl on the N slope of the Kuh-i-Jupar in the catchment area of the glacier tongues which have produced ice-marginal ramps in the montane foreland (Fig 22–26). These lateral striations (Glaciated rock faces ● with deep striation carvings ⇐ and even higher polishing ●) form part of the related series of Pleistocene glacial forms of this glacier (see also Fig 28 and 29) extending out into the foreland as far as the lowest ice terminal position. Photo: M. Kuhle

maximum, confirms the existence of an extended piedmont glaciation, in terms of a corresponding accumulation zone.

The complex of features which describes the typical structure of IMR as well as its genetic morphological relationships thus includes fifteen specific indicators. The certainty of interpretation at this stage of empirical field investigation rests on the broad similarity of the phenomena with those of the classical European glacigenetic morphology (nature of moraines, striations etc.) as well as on the high degree of correlation of these elements in the sense of 'the system of glacial forms' (Penck 1901–1905). They thus appear as able to be treated as homologues according to the homologue criteria of Remane (v supra). Additional support results from the frequent repetition of character combinations in the various valleys of the northern and southern slopes of the mountain massif – which are thus independent of each other – and in the clearly separable deposits of a younger and an older phase of glaciation. (Since there is a partial superposition of criteria – roches moutonnées e.g. may not be separable into older and younger – the principle of 'identical repetition' should not be overstressed; the data for the IMR of the Kuh-i-Jupar included here will enter the final calculation with the factor two (a = 2) i.e. two identical but independent repetitions, one north slope and one south slope).

Fig 28
A view towards the uppermost catchment area at 4135 m altitude of a classical glacigenetic trough valley from 2870 m in the Kuh-i-Jupar N slope; today it is quite free of ice and even snow (Dare Karson, SE Zagros; locality see Fig 22). The structural asymmetry of the valley resulting from the westward dipping massive limestone is almost completely transformed by the glacial U-shaping. From 2800 m downwards there is incised into the rock floor of the trough a narrow subglacial meltwater channel (↓) confirming the equilibrium line altitude a few hundred metres above suggested by the foreland moraines (Fig 22–26). In general erosion by subglacial meltwater occurs 100 m to 300 m below the equilibrium-line associated with mountain glaciation. Photo: M. Kuhle

Fig 29
Remains of lateral moraines on the limestone slopes of the Dare Karson (-valley)on its orographical right bank showing an erratic Kerman conglomerate block (figure in foreground). (N slope of the Kuh-i-Jupar; locality see Fig 22). The erratic block has been carried here over a distance of several kilometres across the lowest part of the valley from its left bank – only there does the Kerman conglomerate occur (×). This is further supporting evidence for a Pleistocene glaciation of the Kuh-i-Jupar. Photo: M. Kuhle

Up to this point of field investigation it had to remain uncertain if the depositional form of the IMR was merely a regional occasional variation of the 'glacial sequence' or if it was of supra-regional significance in a deterministic, law-like sense as an typical indicator of semi-arid piedmont glaciation. However, this question was solved by the discovery of 13 further IMR occurrences.

Central Andes: the Uspallata Basin (32° S–33° S)

A first complete repetition of the character coincidences found in the Kuh-i-Jupar occurs on the east slope of the Cos. del Chacay (NE of the Aconcagua Massif). The IMR complex deposited there (Kuhle 1984a; 1989c: Fig 8, 9, 10) marks the terminus of a 15 km long glacier which reached the Uspallata basin during a high-glacial depression of the ELA of 1400 m (at 3400 m asl). This level of ELA and thus homologue 11 (which requires several observations for its confirmation) is evidenced by the nearby Rio Mendoza glacier for which an ice thickness of at least 1020 m with a length of 112 km is supported by many transported erratic blocks (Fig 31 up to 1000 m above the valley floor 7 km below their source area; Kuhle 1984a, 1989c: Fig 12 and 13), striated erratics (ibid: Fig 11), trimlines, lateral-, medial- and end-moraines (Fig 13 and Fig 14) (Kuhle 1984a).

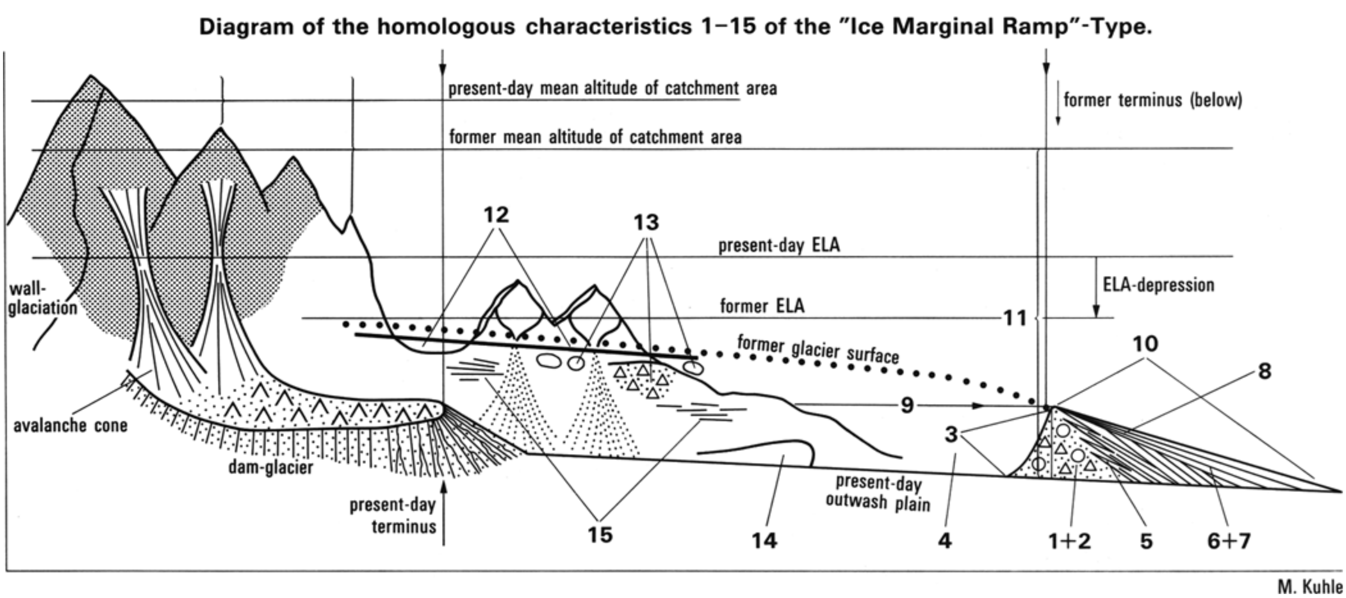


Fig 30 The central importance of this combination of characteristics lies in the spatial arrangement of its parts.

Fig 31
Erratic blocks (up to 4,5×3,3×1,5 m in extent) at 3135 m asl, 600 m above the floor of the valley of the Rio de las Cuevas in the Aconcagua Group (Andes 32°–33° S). These are granites and granodiorite blocks transported at least 5 km down valley from their outcrop; here they rest on in situ Palaeozoic and Cretaceous red sandstones. These erratics indicate that this today subtropically arid valley had within it at least 600 m of glacier; its flanks, as seen in the valley side opposite, have been greatly altered by post-glacial weathering and covered with young detritus. Further erratic blocks have been found at the same altitude on the opposite valley side (↓).
Photo: M. Kuhle

Northeastern Tibetan Plateau
(38° N–40° N and 34° 50' N–36° N/95° E–102° E)

Extensive IMR occurrences in a typical association with other glacigenetic indicators were found in four separate massifs in the NE of the Tibetan plateau: – Xinghai-Nan-Shan, Kuenlun-Shan, Datsaidan-Shan, Qilian-Shan. In part these consist of adjacent collections of 10, 20 or more single forms arranged around the peripheries of former glacier tongue basins over tens of kilometres in the mountain forelands (Field evidence in Kuhle 1987a and b, summary account in Kuhle 1984b, 1989c). The depression of the glacier equilibrium line derived from this evidence is on average 1100 m below the present one. With this value, the IMR of the NE Tibetan border mountains fall in line with the reconstruction of the broader climatic environment of High Asia during the last glacial maximum which was characterised by a plateau glaciation of central Tibet and a network of ice streams in the Himalaya and Karakorum and has been described in many field studies by the author since 1976 (summaries in Kuhle 1988b, c) and confirmed by the older and more recent literature (cf. Kuhle 1988d: Fig 3).

Tian Shan – Issy-Kul (42° 30' N/77° E)

The major occurrence of IMR so far discovered is in the seven massifs in the Tian Shan. M. Grosswald was the first to become aware of the morainic character of the deposits. The great similarity of these abnormal ramp-like deposits, with their overlay of glacifluvial sandr, to IMR as described by the author resolved his own uncertainty regarding a glacigenetic interpretation of them[14]. A detailed description of the forms is not yet available (Grosswald and Kuhle – in preparation). Here are to be found large IMR with all their characteristic morphological and sedimentological properties in the foreland some 7 to 20 km from the rocks in situ on the S slopes of the northern Tian Shan and the N slopes of the central and S Tian Shan. In places they extend distally to the 180 km long W–E extending Issy-Kul (lake) and lie at 1600 m to 1800 m altitude as 20–25 separate morphological complexes related to seven mountain massifs over a distance of a total of 300 km N and S of the lake. Their relationship to the height of the glacial catchments that fed them is quite clear because of the favourable topographic arrangement of the W–E extended mountains since they generally are to be found where such areas reach above 4000 m; otherwise they are lacking e.g. for 80 km at the E end of Issy-Kul. The resulting uniformity of ELA-depressions confirms the glacigenetic interpretation of the deposits which, as is indicated by their good preservation, are all contemporary with the last glaciation. Both Types A (Fig 21) and B (Fig 32, 33 and 34) occur, and the flatter transitional cone (B) has to be regarded as the end stadium resulting from the long-period stability of the foreland ice margins during the highglacial maxima. They indicate a depression of the climatic ELA of at least 1000 m i.e. to about 2900 m asl. The resulting absolute height of the ELA gives a further confirmation of the glacigenetic implications of the IMR with respect to the large-scale trends of the meridional, planetary ELA-gradient.

Fig 32 Terminal-moraine ramps in the S montane foreland of the N Tian Shan on the N shore of Issy Kul based at 1630 m altitude (42° 50' N/ 77° E, near the settlement of Cholpon Ata) forming the elements of an ice-marginal ramp of the type A (Fig 21 Type A). These morainic slopes considerably over 100 m high slope down into the glacier tongue basin (middle ground, near left edge) and are formed of erratic granite material in part of large volume. The accumulation of large blocks increases upwards towards the ridge of the moraine (foreground and middle ground). The glacigenetic nature of these sediments is vouched for by their form and plan arrangement and also their position in relation to the younger late glacial moraine deposits (up to 400 m high) at the exits of the mountain valleys in the background (▼). Photo: M. Kuhle

The present depression of the ELA from the Kuen-Lun mountains (800 km S) to the Tian Shan amounts to 1200 m, denoting a gradient of 150 m/100 km in comparable precipitation conditions. For the last glacial maximum the same gradient of the ELA from the Kuen Lun to the Tian Shan is supported by the IMR described around Issy Kul. This planetary high-glacial ELA depression from N Tibet to the central Tian Shan places those IMR in a supra-regional context of glaciation which has multiple cross-sectional relationships e.g. the further elevation of the ELA towards the Himalaya arc in the S or a comparable depression of the ELA in the Bogda Shan (E Tian Shan) etc. and thus confirms the glacigenetic interpretation of the IMR type on an increasingly broader empirical scope.

Finally some striking characteristics of the realm of glacial forms extending from the piedmont IMR deposits to the individual massifs are indicated. For example, the S slope of the Yok-tar massif (4770 m asl, north of Issy-kul near Cholpon Ata) shows hanging trough valleys with classical polished U-profiles. In the valley exits in the foreland are 400 m high morainic hills of clear morphological and sedimentary character (Fig 32).

In the massif south of Pakrowka, reaching 5216 m S of Issy-kul, very large IMR (Fig 33) were traversed and mapped in detail together with the corresponding valley system reaching up to more than 4000 m with its still glaciated culmination of the ridge. Extending from the high plateau of the Tian Shan (N of the Arschirak chain, 3600 m–4000 m high) down to the Issy-kul across several gentle pass depressions in the N slope of the mountains the completely etched trough profiles are marked by locally well preserved trimlines and glaciated rock surfaces. There is little post-glacial (Holocene) filling of the valley floors with gravel or mudflow – and talus cone material and even this decreases correspondingly in upvalley direction. Glacigenetic marginal smoothing and more or less well-preserved rock polishing continue to the exit of the Jomke-Sulzu valley at 2200 m asl. Further indicators were found in the nearby valley outlet as morainic erratic blocks with volumes 5×4×5 metres on both flanks 110 m to 250 m above the valley floor. These are gneisses and granites derived from up valley with good edge rounding, locally embedded in a fine ground matrix of a lateral moraine ridge. Quite apart from the unambiguity of these discoveries, their combination with the level of the highest lateral morainic ridges on the slopes which continue as very thick glacigenetic marginal formations for more than 10 km into the foreland to terminate at the high-glacial IMR gives proof of true interdependence in terms of a glacigenetic origin. This must be a series of younger i.e. late glacial lateral morainic deposits which extend, as in similar topographic situations, in continuation of the montane valley tract along the narrow post-maximal glacial bed (recessional moraines) to the neighbourhood of the former broad lobed margins of the high-glacial terminus with its IMR deposits (cf. Fig 33).

Fig 33 Ice-marginal ramps of the transition cone type (Fig 21 Type B) in the N foreland of the Central Tian Shan based at 1650 m altitude (between the settlements of Przheval'sk and Pakrovka on the E part of the S shore of Issy Kul 42° 20' N/78° 10' E); in the background the still glaciated massifs rising to 5216 m through which flowed the net-like ice stream of the tens of kilometres-long outlet glaciers from the 3500 m–4000 m high central Tian Shan plateau. In these montane valley can be found both trough profiles and glacial striations as well as erratic blocks high on the flanks of the valley exits into the foreland. The associated Pleistocene piedmont glaciation is substantiated by ice-marginal ramps several hundreds of metres thick (middle ground). These ramps cutting out towards the mountains are connected to the valley exits by late glacial morainic accumulations (×). The settlement in the foreground is sited on a fan-like outwash field (a Kegelsandr). On the right hand margin of the picture occur terraced ice-marginal ramp deposits (○) which correspond to the ice-marginal ramps on the orographic right. The lowest ice tongue which occurred flowed down between the two ice-marginal ramps and lay with its decreasingly lower and retreated margin against their sides (cf Fig 34), forming these terrace edges with slopes of 7°–10° (↓↓↓). These ice-marginal ramps of Type B (cf Fig 21) belong to a transitional cone of a long-lasting and only slowly down-melting ice margin. Photo: M. Kuhle

Subrecent and recent (present day) IMR

According to the criterion of transitions (third criterion of Homology) intermediate forms contribute to the derivation of homology of complexes of characteristics. In this sense we quote the IMR of the north slope of the Shisha Pangma and Gang Benchen (Kuhle 1988a: 483 ff. Fig 40–44; 1989c Fig 17–19) which are today reached by the greatly reduced glacier tongues and thus allow demonstration of their undoubted relationship to the glacigenetic complex. In several details they depart from standard as, for example, in being more like medial moraines between adjacent glacial tongues and locally attach to the mountain front. Because of their high location within the present periglacial region (above the permafrost boundary) and therefor being affected by gelifluidal detritus movement, the formation of small meltwater channels within them is also prevented.

Today on the glaciers of the Nanga Parbat and the Kangchendzönga massif the process of glacifluvial superdeposition of debris on the outer moraine slopes from the level of the ice surface can still be observed (Fig 35). The lesser stability of the ice margins and the narrowness of the valley in which they are deposited results in the angle of deposition being very steep (19°–28°), corresponding to the juvenile stages of the IMR in the piedmonts which there from the basal accumulation nuclei (cf. Fig 21).

The Random Probability of the Morphological Type IMR

Evidence in geomorphology is of necessity based on qualitative argument. Due to the basic polymorphism of form elements reflecting their historical (individual) development as a random variability the derivation of quantitative standards is impossible and so the concept of the type is irreplaceable. From the re-occurrence of coincident characteristics a hierarchy of typological units derives whose lawlike interdependence is explained by an uniformity of the underlying causal nexus. The certainty of the evidence is thus proportional to the number of characteristics as well as their repetitions. The quantification of the lawlike probability thus depends not on the items of evidence alone but is measured solely by the occurrence of those indicative relationships which by means of empirical studies have been determined as the qualitative units of the inductive key.

The type IMR is generalised from the field evidence by means of fifteen individual characteristics of position and structure (G) (Fig 30) which may be treated as homologues and whose interdependence is confirmed by fifteen independent recurrences (a). If we accept a probability of occurrence of 1/2 for each characteristic (i.e. only one alternative) the probability of the random hypothesis can be derived from the formulae (4) and (7) as $2^{-15\cdot 15} = 2^{-225} = 1/5.39 \ldots \cdot 10^{67}$ [15]. From the formula (6), in its simplified form $P_{ga} = 1/(1 + P_f^a)$, since so far no case of negative coincidence has occurred, the probability of a lawlike causal nexus can be calculated as $P_{ga} = 1/(1 + 0.5^{225}) = 0.99999 \ldots$ (the first digit less than 9 occurs in the 68th decimal place). The Type IMR is thus assured as a lawful form element of a specific complex of glacigenetic processes with great certainty (i.e. with an approximation of P_g max $= 1$ with 67 places after the decimal point).

Further confirmation is to be expected from continuing investigation of the Asiatic and South American mountains and their forelands which have so far hardly been examined from this point of view. The proved correlation of IMR and glaciations needs to be considered as an essential element in the reconstruction of palaeoclimatic conditions.

Conclusion

This investigation based on information theory transforms the elements of proof in geomorphology – instanced by the positional relationships of characters indicative for former glacial systems – into a numerical probability value. The central paradigm is that of homologue types which stand for specific combinations of polymorphous characters, the deterministic correlation of which is traceable to their functional dependency on a specific process system. Thus not only the reality of former phenomena, which to some degree are not consistent with the principle of uniformitarianism, can be made certain but also geomorphological occurrences with few repetitions in space and time (i.e. during the Pleistocene glaciation) are shown to be empirical types and associations with great statistical assurance. The problem of proof in geomorphology lies in the historical and topographical uniqueness of its subjects. The possibility of experimental simulation and the derivation of exact laws is thus narrowly restricted. However, the reciprocal relationship between induction, formation of complex types and hypothetical deduction provides empirical field studies with a method of proof, the probability content of which may be equated to the lawlikeness derived by experimentation. The establishment of complex types, defined by the empirical correlation of specific characters can not be replaced by the statistics of standardised i.e. theory-neutral quantifying data as has recently been advocated (Barsch 1989; Stäblein 1989) with the vague implication that such agglomerations of earth-science data may at some time by themselves lead to ecologically relevant conclusions. Here the study of forest decline due to acidic precipitation provides a parallel, which shows that the use of statistical data without correct determination of its causal interdependence leads to false interpretations and that only the establishment of qualitatively characterised data complexes (case studies as the basis for the construction of types) can show the direction for statistical analyses able to provide valid conclusions (Ulrich 1989, 1990).

Fig 34
Ice-marginal ramps (on the orographic left) with a basal height of 1650 m asl in the N foreland of the S Tian Shan 50 m above the lake level of the Issy Kul to the N (42° 10' N/ 77° 37' E, near the settlement of Barskoon). The highest point of the glacial catchment area reaches an altitude of 4626 m. The successive development of the ice marginal ramps can be recognised by the stepwise deposition of lateral morainic ridges of several generations. The youngest and therefore geomorphologically most freshly preserved late glacial marginal moraine (↓) is evidence of a piedmont glacier only half as high as that of the surface of the high-glacial tongue.
Photo: M. Kuhle

Fig 35 The moraines of the present Jannu glacier with its catchment area up to 7000 m asl (above the clouds on the left the 7710 m high Jannu, Kangchendzönga Massif, east-central Himalaya 27° 40' N/88° 05' E, taken from 4200 m). These end-moraines provide (in terms of the principle of uniformitarianism) a youthful stage of the formation of ice-marginal ramps. Today the glacier surface covered with superficial moraine has sunk down some 100 m. When it reached the upper edge of the frontal moraine its surface-flowing meltwater discharged steep skirts of outwash to form the youthful stage of these glacial ramps. The presence of the narrowly incised fluvial gullies (↓↓) suggests the process. In the righthand half of the picture these skirts of outwash are rather less steep and become even flatter with increasing accumulation of outwash (⟹). An angular ice-marginal ramp will be formed between two outlets from the glacier tongue basin (↑→).
Photo: M. Kuhle

Footnotes

1) The separation of classification from comparison, such as Carnap requires, is however impossible, since each is a complimentary aspect of one and the same experience and thus it is merely a disjunction introduced by the logic of speech in two aspects always realised together (cf. Riedl 1987: 30 ff.).

2) The traditional overvaluation of quantification can be traced back to Plato and is due to the idea that the strikingly immanent logic of quantitative or mathematical axioms is proof of their high level of realism. Gauss was one of the first mathematicians to cast doubt on the applicability of the Euclidian axioms (that angles sum to 180°, or the axioms of parallelism) to real spaces and suggested that the validity of a non-Euclidian geometry should be empirically checked.
Much more frequent, and corresponding to the Carnap postulate, are such positions as those for example of the controversy between Lord Kelvin and Darwin. Before the effects of radioactivity within the Earth were known Lord Kelvin derived an age for the Earth based upon the laws of cooling for a body of its size of between 24 and 100 million years. Since the logic of his mathematical derivation was incontrovertible he completely discounted the value of several thousand million years based by Darwin on his 'inexact' theory of evolution (from Mayr 1984: 341 f.).

3) This process of rationalistically derived construction of ideal quantities and axioms, whose statistical variability is considered accidental, is ontologically related to the concept of the 'Idea' in Plato. This relationship is explained by Mayr (1984: 38 f., 31–37). However, the Platonic 'Idea' cannot generally be taken as synonymous with 'Type', an equivalence falsely accepted by Mayr when he explains the danger in the formation of typological concepts – to fall into a denatured dogmatic 'essentialism' – as one of its unavoidable constituent elements. The type-concept used here is different and is explained below.

4) An example, quite clear because of its distance in history, showing the consequences of the fossilisation of standardised definitions, occurs in medieval scholasticism: the Aristotelian system – based on empiricism and aiming at the acquiring of knowledge – became in scholasticism a dogma where each new experience by means of immanent exegesis had to be forced into an unalternable 'scheme' or, in the case of contradiction, the observation had to be discarded as 'untrue'.

5) This reciprocal relationship, in which hypotheses derived from empirical studies show the way to the determination of the constitutive characteristics and those in return are used as verifying indicators for the further confirmation of underlying hypotheses, brought to the concept of Type a reproach of tautological circularity. In fact, it is not a matter of a "circular, but more of a helical process. Each turn resulted not in a return to the beginning but rather to a progression to the optimisation of the acquisition of knowledge" (Riedl 1987: 161). A classical example of this process is the deciphering of cuneiform writing by Grotefend in 1802 (from Ceram 1956: 242–9). His starting points were quite unproven hypotheses about the letter equivalents of the signs, the direction of reading, their liguistic affinities and their content. The application of these hypotheses to the available inscription and their stepwise confirmation provided the possibility of extended predictions (= hypothetical deduction) now however based upon the letter-, syllable- and word-meanings so far derived: "Since the correct deciphering of the names would provide me with more than twelve letters, which were all but one contained in the King's title, it was thus necessary to find out the Persian form of the name which was only known in the Greek idiom in order to determine correctly each character of the royal title and thus to decide the language in which the inscription was written . . .: this provided me with the first seven letters of the name 'Hystaspes' in the Darius inscription, the three last having been already found by comparison of all the royal titles" (Grotefend 1837).

6) It has only recently been emphasized (Riedl 1987: 125) that Goethe, who described the intermaxillary bone in man and thus contributed to the theory of evolution, was the first explicity to show the scientific significance of the concept 'Type' and its empirical basis (in his 'Introduction to comparative anatomy', 1795): "It already follows from the general idea of the type that no single animal can be set up as an example of it; no singularity can give the pattern of the whole . . . From experience we must first learn to know those parts which are common to all animals and how such parts differ. The idea must hold for all of them and provide a genetically derived general picture. Although the establishment of such a type, is only provisionally we can very well use for the further investigation of its validity the usual methods of comparison . . . With the establishment of a 'type' in the sense of a general standard, we assume, that there is a certain consistency in nature and we trust, that all cases to follow will be in conformity with a certain law . . . Classes, genuses, species and individuals are just cases of the law; they are contained in it but themselves neither contain or provide it".

7) The dangers which lie in economic planning based upon reductionistic information content were described by Kuhle 1989a, b.

8) This is analogues to the assertion that an original work of literature or art is 'more correctly' represented through the filter of interpretation than in itself.

9) The investigations of Zilliacus (1987) on the problem of annual moraines using the Finnish de Geer moraines can here be referred to as an example. The field work was carried out within the core area of classical Ice Age deposits (S Finland) and used two- and three-dimensional orientation analysis as well as petrography, granulometry and morphometry. By making comparisons of e.g. the cumulative particle size curves within the moraine cross-sections it was possible to extrapolate backwards to the formation history of the de Geer moraines, which, together with the other indicators, led to their interpretation as sub-glacial deposits *without* value for geochronology (ibid: 22 ff.). But at the same time the particle-size curves (ibid Fig 14, 15, 19, 44, 45) provide no kind of *differential diagnostic* information, since they are identical with those e.g. of the glacifluvial outwash which Kuhle (1990: Fig 19, 20) investigated on the north slope of the Kuen Lun.

10) Decreasing knowledge of those special scientific methods of geomorphology goes with an increasing misunderstanding of their effective applicability. The labelling as 'old stuff' (Derbyshire 1987, pers. com. on occasion of the Karakorum and Himalaya meeting March 1987 in Leicester UK, with regard to the evidence of glaciation in the Skardu basin published by Oestreich in 1906) is already considered as sufficient legitimation to suppress even those results of classical geomorphological analysis which anticipated the investigations of present fieldworkers – as if only 'modern methods' of statistical quantification could be of scientific relevance. By now it has become a widely adopted technique of modern scientific practice to ignore the results of scientific investigation if they are not dressed up in pseudo-exact quantifying jargon.

11) The founder of the calculus of probability, Blaise Pascal, had already in the mid-seventeenth century made this basic distinction between mathematics and holistic demonstration when he differentiated between the spirit of geometry and the spirit of finesse (Béguin 1959: 115 f.).

12) Concern with the clarification of the concept of Type is in no way a consequence of modern scientism. The question of the relation between ideal categories and reality has continued since the classical phase of Greek philosophy in both ethics and the theory of knowledge. Plato (427–347 BC), strongly influenced by the numerical ideas of Pythagoras, took the view that the ideas i.e. the categories (peculiar to mathematical constructs) attained the highest reality. The participation of space in the ideal mathematical formulation produces the recognisable features which still could never realise those ideas existing independently of them in their full purity. In contrast to Plato, Aristotle (384/3–322/1 BC) was provided with an extensive empirical knowledge on natural history (special biology). He criticised the Platonic dualism between Idea and Appearance and opposed it with the principle of entelechy, in which the generality is only realisable in individuals, whereby the resistance of matter impedes a pure realisation of the form by the attribution of accidentials. Scientific experience and proof consisted, according to him, of a deduction of the special from

the general. The use of the syllogism was therefor the central method of the Aristotelian system. Investigation however, says Aristotle, has to follow a direction contrary to that of deduction: finished science is apodictic (i.e. deductive) but it develops by the epagogic (i.e. inductive) method. The deduction of a concept (definition) occurs when it is formed from a general one (the next higher category, genus) by the addition of a specific characteristic (differentia specifica), whereas abstraction to form general ideas proceeds by the disregard of such specifications. There is however beyond the conceptually determined individual a whole gamut of categorical ideas which is just that of Reality. In critical contrast to Plato, Aristotle showed, on the grounds of impossibility, that qualities could not be developed analytically from quantities, since quality is in fact something new, for which the quantitative relationships are just the medium of realisation (cf. Windelband-Heimsoeth 1957: sections 11, 12). The question of the logico – metaphysical meaning of the idea of categories (universalia) and their relation to reality was taken up anew by the medieval controversy over universals. The opposed positions referred either to Plato (realists) or to cynical/stoical ideas or to Aristotle (nominalists, according to the fragmentary scripts by which he was recognised). Extreme realists, later to be continued as idealists designated the universals as independent substances whose reality was greater the greater their degree of abstraction. The extreme nominalists recognised only individuals as real and universals simply as collective names, sounds *(flatus vocis)*. The later position of terministic nominalism (William of Occam ca. 1300–1350) then provided a real impulse for the development of empirical natural science. According to Occam all general concepts were simple 'signs', 'terms' i.e. supposed imaginative substitutes for real conditions. Reality is entirely in the specific individual. Thus inductive empiricism, based on the possibility of measurement and quantification, was admitted as the forefront of deductive argument which had been the dominant doctrine of scholasticism as the result of a misunderstanding of Aristotle. Occam held that the reality of the original forms was recognised intuitively i.e. without help from 'species intelligibiles' (first intention) and is the basis of 'real' science (extended into the positivism of the Vienna school, Carnap, Schlick, Wittgenstein etc.). 'Rational' science refers to the immanent relationships between these intentions (second intention) and is therefor divorced from reality i.e. arbitary ('ad placitum instituta'; the earlier form of the conventialism advocated by Poincaré 1928). All successive concepts in the theory of knowledge may be understood as derived from this basic position with varying weighting and combinations of its elements. The dualism between empirical individualism and abstracting systems of ideas, which lack logical principles of construction, must be endured as a priori, and still provides as an apparently insoluble antithesis the (often unreflected) basis for the differences in the theory of knowledge found in the scientific effort of today (the problem of verification, evidence and conclusiveness). The first synthesis to be provided was that of 'hypothetical realism' in terms of a biological substantiation of the theory of knowledge (Lorenz 1941, 1973; Riedl 1981). In this the a priori categories of cognition are explained as the a posteriori of phylogenetic acquisition of knowledge. They are subconscious hypotheses which have become accepted as a probability calculus by interaction with reality under the pressure of selective evolution and have successively developed into a genetically fixed underlying program of our physiological equipment. Thus the nominalist method of acquisition of knowledge appears to be an individualistic (ontogenetic) equivalent to the idealistic concept formation based on hypotheses which have also developed empirically, yet during the period of phylogenesis. In both cases the probability content is the underlying measure of the conformance with reality.

13) It is however a fact that in biology homologies attain much higher levels of complexity, because here the phenomena of codified adaptive modification and their tradition provide a reservoir of genetic information, which, accumulating over 3000 million years as a self-canalised learning process, has no correlate in dead matter which shows only process patterns directly related to the environment but not those determined by internal selection (cf. Riedl 1975: 217, 298). Tradition plays only a passive, not active role in geomorphological phenomena. Thus the principle of uniformitarianism formulated by Lyell in 1830 allows the late-palaeozoic morainic material of 650 million years ago to be considered as directly homologous to that accumulated in Pleistocene times (1 million to 10,000 years ago) in that differences between them are regional (e.g. different parent materials) rather than the effect of 'genetic development'.

14) M. Grosswald is gratefully acknowledged here for the invitation to an expedition to the Tian Shan (autumn 1988) and the Soviet Academy of Sciences is also thanked for its financial support.

15) This is the random probability of fifteen repetitions of fifteen coins thrown at the same time always producing 'tails'.

16) The problem of the characterisation of glacigenetic deposits is summarised by the Swedish specialist on moraines J. Lundqvist (1989: 9 ff.) as follows: "Existence of striated boulders and some sedimentary structures are indications, but no single piece of evidence is conclusive. One complication in the identification of glacial deposits is, that they do not follow sedimentary laws. From the sedimentological point of view any kind of sediment can be deposited by a glacier. . . .
According to the definition adopted by the Till Work Group of the INQUA Commissions on Genesis and Lithology of Quaternary Deposits 'Till is a sediment that has been transported and is subsequently deposited by or from glacier ice, with little or no sorting by water' (Dreimanis, 1982). This is a very general definition, which seems to be the only one that can be reasonably widely accepted. There is only one vague point in it: how much is 'little sorting'? . . . If this definition of till is accepted, we find a great variety of tills. . . . If we consider all the parameters controlling till formation we find that there are theoretically at least thirty varieties (J. Lundqvist 1984). . . . The problem of the definition of till exemplifies a general problem: ubiquitous gradual transitions between the different types of deposits. . . . We may argue forever about problems of where to put the boundaries between different deposits, but we will probably never reach a consensus of opinion. . . . In the interpretation of deposits, sedimentological analysis is essential. It helps to explain the formation and origin of different strata. However, such an analysis requires good sections and a knowledge that they show representative sequences of strata. In vast areas this is not the case. . . . Then we have to trust the surface and landforms. Therefore a good understanding of glacial landforms is essential in glacial geology".

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