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FOURTH INTERNATIONAL CONFERENCE ON GEOMORPHOLOGY - Italy 1997
Session: Glacial Geomorphology

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GLACIAL GEOMORPHOLOGY

Glacial geomorphology occupies a key position in the history of the study of global climatic change. Central to this relationship is the recognition and analysis of the distinctive sedimentary suites left behind by down-wasting glaciers and ice sheets. Both glacial deposits and glacial erosional landforms have provided information on the extent, regime, and movement of former ice masses. Glacial geomorphology has grown in step with advances in pure glaciological theory; and the development and testing of models of former ice bodies have had to meet the constraints of both dynamic glaciology and glacial geomorphology.

The diversity of scientific subjects involved in glacial geomorphology is impressive. For example, glacial geomorphology is used to constrain limits of past climatic changes (through studies of equilibrium-line altitudes (ELAs)), to explain spatial and temporal erosional patterns, and to assist in the recognition of detailed variations in the sedimentology and structure of subglacial sediments, often on a very fine scale. It is this great range that brings glacial geomorphology into fruitful interfaces with many other disciplines (fig. 1). Its sensitivity as an indicator of past climatic changes explains why the elucidation of past glacial events has, and still remains, the dominant *raison d'être* of glacial geomorphology.

Analysis of glacial bedrock forms has always been an element in attempts to infer past earth surface conditions, but the information stored in the landforms of glacial deposition has been proportionately more fruitful. Studies of depositional landforms and sediments have yielded much valuable knowledge over the past quarter of a century, and understanding of the process origins of glacial sedimentary landforms has been advanced.

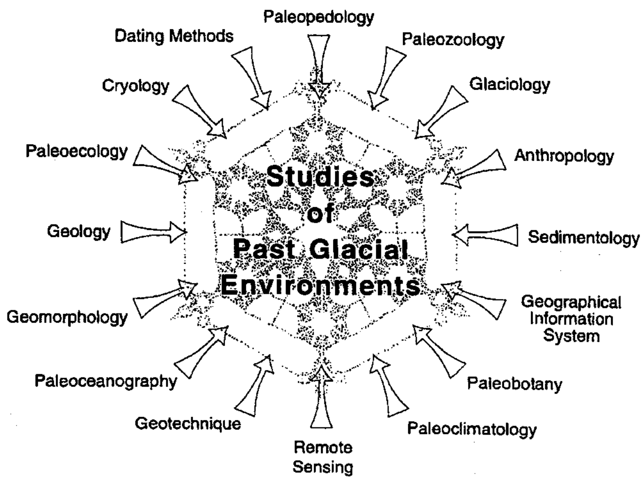

FIG. 1 - The multidisciplinary nature of the study of past glacial environments. (After Menzies 1996).

Glacial sediments may represent the most complex of all terrestrial sedimentary environmental systems (fig. 2). Such complexity is a challenge to students of earth surface processes, as well as to a range of cognate disciplines from palaeoclimatology to civil engineering (fig. 3). The suggestion in 1979 that the rheological behaviour of subglacial

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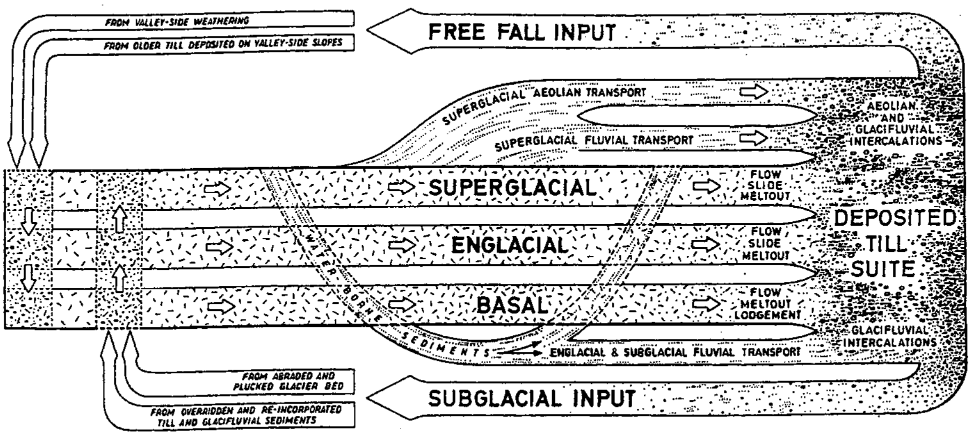

FIG. 2 - A schematic view of the glacial sedimentary system. (After Derbyshire & *alii*, 1979).

sediments may exert a controlling influence upon glacier dynamics (Boulton & Jones 1979) presaged a new vigour in the study of the ice-bed interface in general and subglacial sediments in particular. Recognition in the ice streams within the Antarctic ice sheet of empirical evidence of deformation of the subglacial bed (Alley & *alii*, 1987), and observational evidence in sites as far apart as Antarctica and the Xinjiang Province of western China that «polar» ice (cold and dry-based) may exhibit some sliding, sediment deformation and erosion (Holdsworth 1974; Echelmayer and Wang 1987; Fitzsimons 1996) has added complexity to established models of cold-based glacier-sediment relationships.

Studies of deformable glacier beds have been further stimulated by such developments, and currently range from theories of large-scale erosion and deposition for ice sheets resting on unlithified sediments (Boulton 1996), to a continuum concept applied to all subglacial streamlined bedforms (e.g. Rose 1987: fig. 4), and to detailed studies of fabric and structure designed to infer conditions of deformation as a function of porewater conditions and the three-dimensional stress field (and involving brittle shear or ductile deformation, depending upon the controlling conditions: Benn and Evans 1996). Such studies are important because the glacier sole and the deformable bed constitute a potentially changeable dynamic system in which zones of rapid glacier flow, including surges, may be enhanced.

Reconstructing the transport history of glacial deposits has also been reviewed recently, using clast shape and particle size to discriminate «active» and «passive» flow paths (e.g. Benn and Ballantyne 1994: fig. 5). However, results from the Greater Himalaya suggest that these «active and passive flow path» relationships may be more complex than is currently believed (fig. 6).

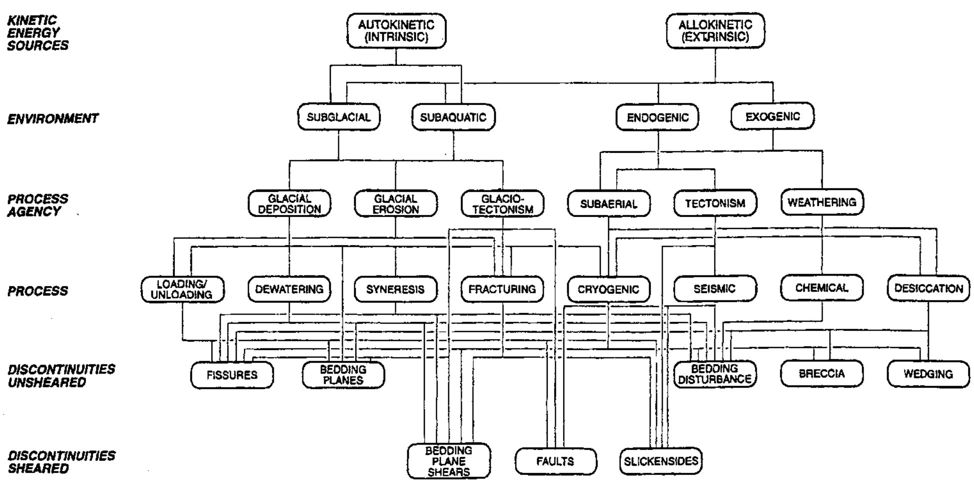

FIG. 3 - Types and origins of discontinuities found in glacial sediments. (After Menzies and Shilts 1996).

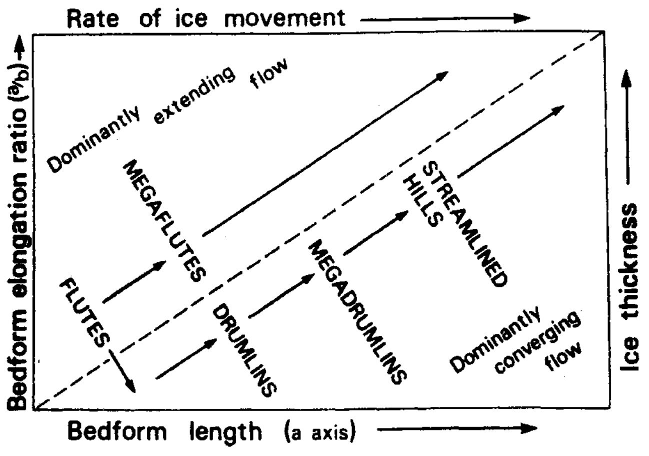

FIG. 4 - Continuum of subglacial bedforms in relation to ice thickness and rate of ice movement. (After Rose 1987).

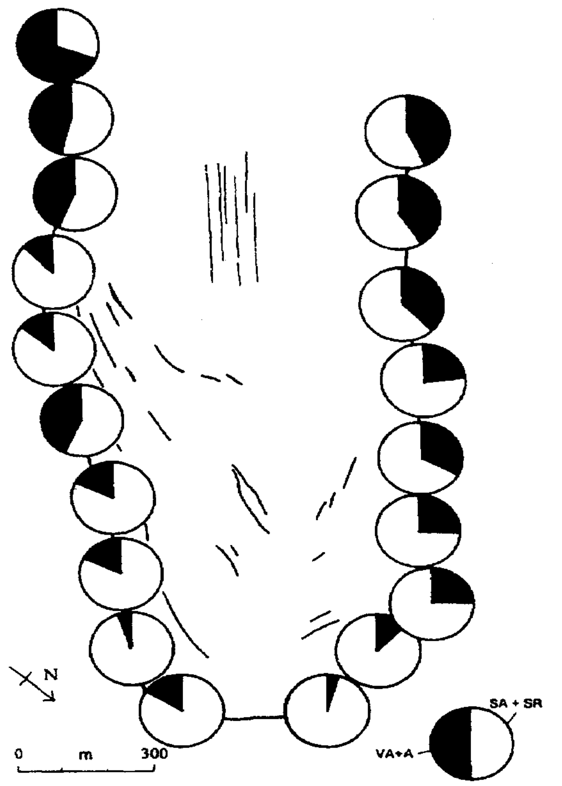

FIG. 5 - Spatial variation in the proportion of very angular plus angular clasts in a moraine of the Storbreen glacier, Norway, interpreted as a surrogate measure of the ratio between passively and actively transported moraine clasts. (After Benn and Ballantyne 1994).

The problem of discriminating glacial from non-glacial diamictons (fig. 7) has been clarified using a combination of sedimentological and geomorphological criteria (e.g. Owen 1994). Nevertheless, a number of uncertainties remain in the discrimination between terrestrial glacial deposits and glaciomarine sediments, in spite of considerable recent advances in our understanding of the glaciomarine environment (e.g. Dowdeswell and Scourse 1990).

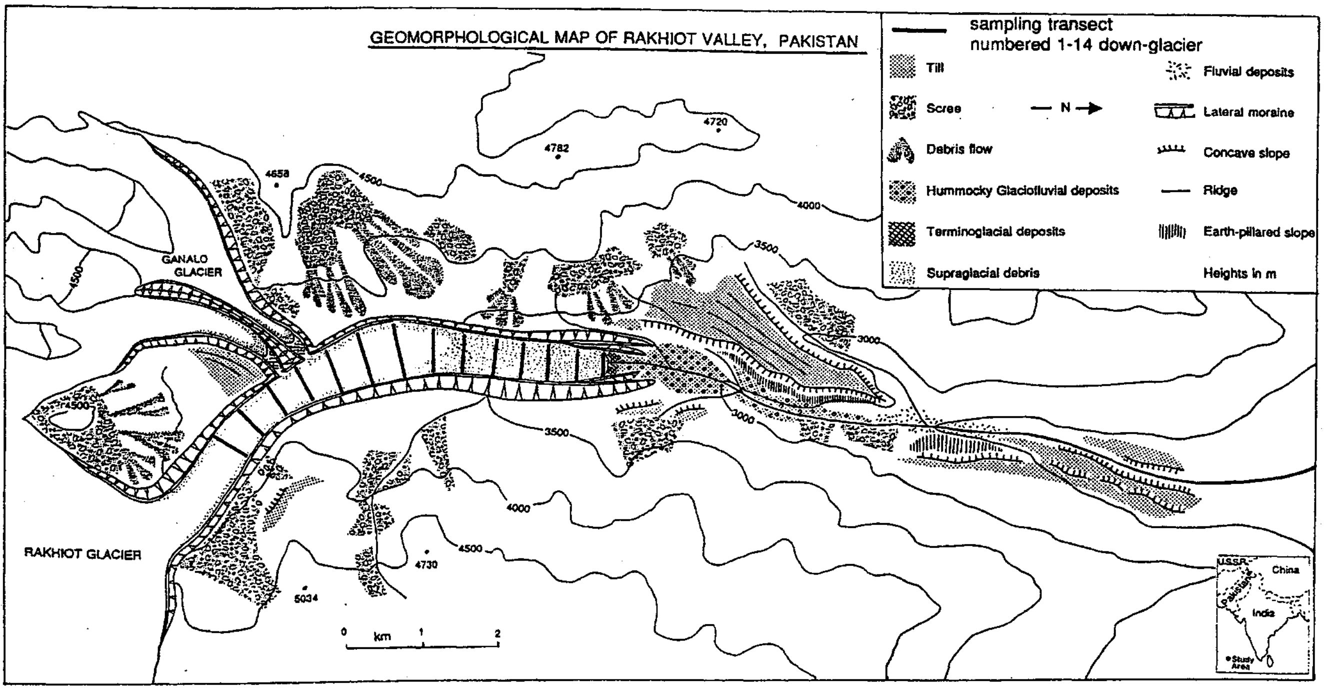

FIG. 6 - Debris pathways, sampling transects, mean particle size distributions and weathering condition of debris of the Rakhiot Glacier, Nanga Parbat, north-west Himalaya. A: Map of the Rakhiot Glacier showing debris sources, glacigenic debris types and sampling lines; B: Mean particle size distributions of supraglacial (top) and subglacial sediments of the Rakhiot Glacier compared to selected glaciers in Europe; C: Percentage of weathered clasts in supraglacial and lateral debris of the Rakhiot Glacier, showing progressive increases in weathering down-glacier in all three cases. (After Scott 1992, unpublished).

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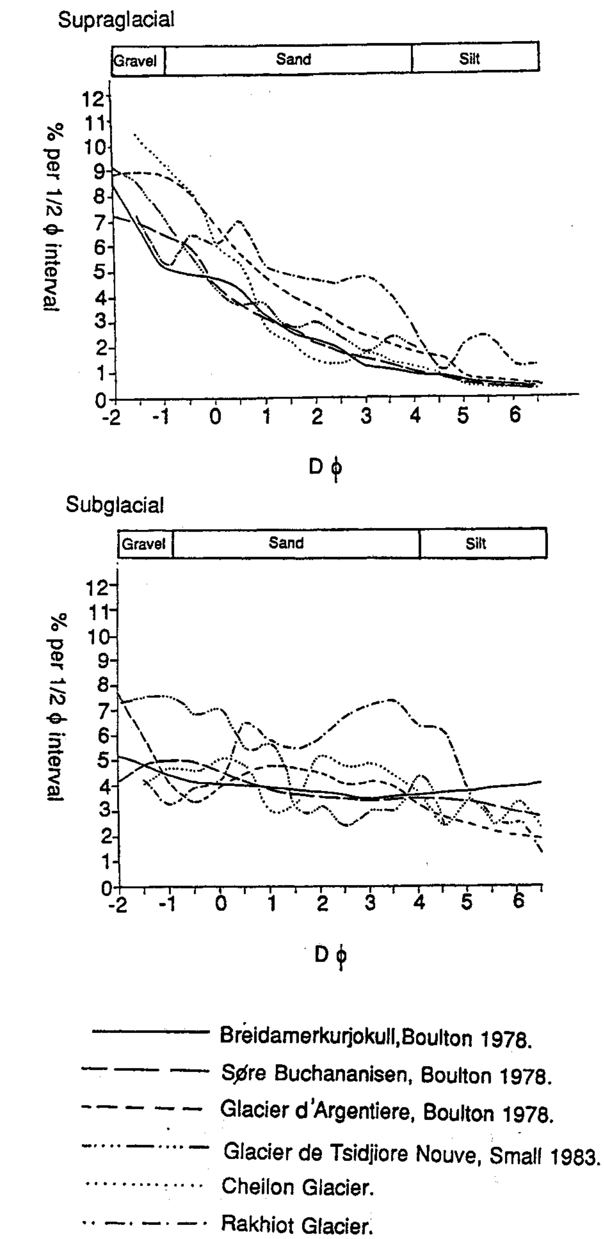

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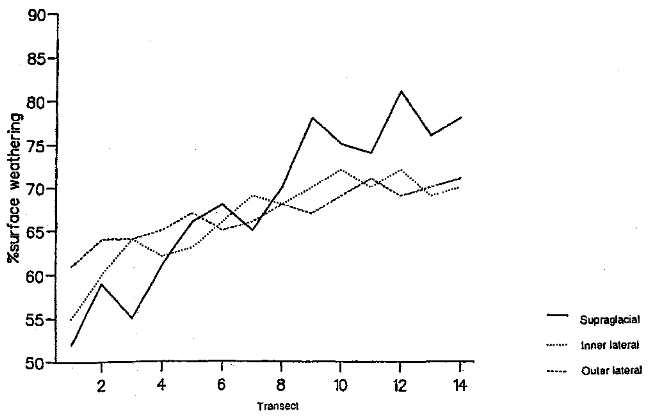

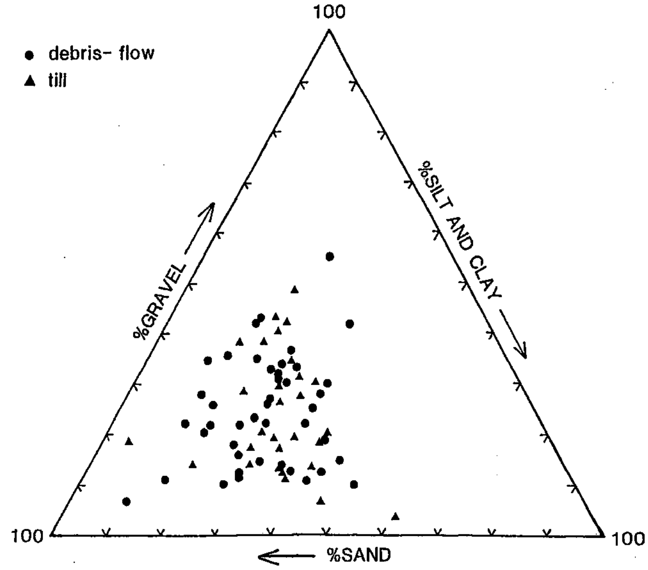

FIG. 7 - Ternary diagram showing the common particle size envelope shared by till and mass-moved debris in the Hunza River valley, Karakoram Mountains, northern Pakistan.

Notwithstanding the substantial advances made in the past two decades, however, there remains much to be learned about glacial sedimentary facies and their relationship to glacial depositional forms. Such knowledge will not only refine our reconstructions of past environments but will also provide valuable models of economic importance, including use in foundation design and geohydrology

Finally, the application of «classic» glacial geomorphological evidence retains great potential for illuminating the palaeoclimatic record (synchronous or asynchronous regional glaciation: fig. 8) and in discriminating between climatic and tectonic signatures in extensive regions such as South America and High Asia. Glacial geomorphology can perhaps best serve society in the future by an even closer marriage with glacial sedimentology, in the advancement of both the pure and applied aspects of landform science.

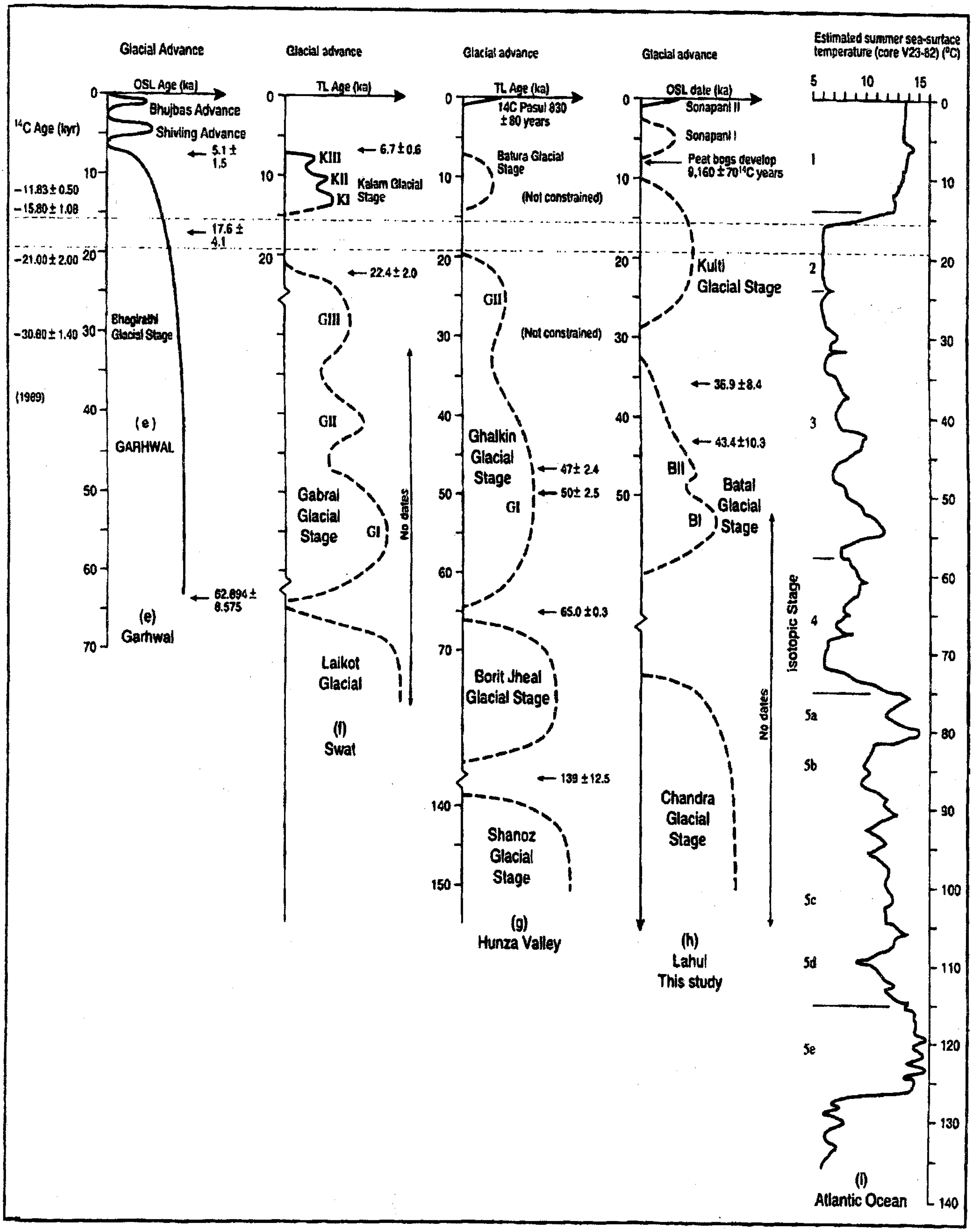

Fig. 8 - Comparison of the extent and timing of glaciation in selected areas of the Himalayas and estimated summer sea surface temperatures. (Abstracted from Figure 21 in Owen & *alii*, 1997).

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CLAUDIO SMIRAGLIA

SYNTHESIS OF THE PAPERS PRESENTED

A total of 33 papers by 58 authors were presented at the Glacial Morphology Session. The authors represented 20 different nations and specifically, Italy (20 authors), Great Britain (13 authors), Russia (4 authors), Belgium (3 authors) and other countries with 2 or 1 authors. As regards the geographical areas taken into consideration, we find Scandinavia and the mountains of Asia in the forefront, followed by Canada, the Alps and the Spitsbergen with 4 or more posters. Other posters dealt with Great Britain, Greenland, the mountains of Spain, the Apennines, the Andes, the Tatra, Iceland, Taiwan and Serbia.

Two of the papers *(The geomorphology and sedimentology of surging glaciers: a Landsystem Approach* by D.J.A. Evans & B.R. Rea and *Termination of Pleistocene glaciation and Holocene environmental changes in the High Tatra* by A. Kotarba) were presented as Oral Papers. The first dealt with the reconstruction of the surging glacier landsystem by utilizing observations on contemporary surging glacier snouts in Iceland and Spitsbergen; examples of the geomorphology and sedimentary structures of possible ancient surge margins in western Canada and eastern England were also assessed using landsystem model. In the second one Late Pleistocene and Holocene changes in both glacial and other geomorphic processes in the High Tatra Mountains have been presented; in particular three stages of the development of the Tatra environment have been distinguished and reconstructed, basing on the sediments of dead-ice depressions and lacustrine deposits.

The other papers were presented in the Poster Session.

The greatest problem in summarizing these posters lies in grouping them by topics. Taking into account the topics dealt with, the chronology of the landforms and the events described, a subdivision consisting of six subsections has been proposed.

The first subsection could be entitled *«Glacial landforms resulting from the interaction between glaciers and bedrock".* This subsection is comprised of seven posters that dealt with ice-scoured landscapes originating from contrasting basal thermal regimes and from the transition from cold-based to warm-based ice sheets. M.F. André presented the poster *Preglacial tors in Aurivaara (Swedish Lappland): geomorphic pattern and glaciological implications* in which the author questions the antinomic view of the tor-like features interpreted in the nordic areas as indicators of cold-based ice conditions, whereas they were used in the southern European mountains to map the Quaternary unglaciated areas; in the author view the Aurivaara plateau represents a smallscale expression of the classic mosaic of scoured and not scoured landscapes linked with constrasting basal thermal regimes. J. Gray, C. Clark, V. Decker, J. Gosse & J. Klein presented a poster about *Patterns of mountain and continental glaciation of the Torngat Mountains, Norther Quèbec-Labrador: the geomorphological evidence for cold-based ice.* They observed extreme contrasts in sediment cover and in weathering of bedrock at difference altitudes; the hypotesis developed is that these contrasts can be related to transitions from cold-based to warm-based thermal regimes at the base of local ice streams. J.K. Hart dealt with *The deforming bed/ debris-rich basal ice continuum and its implications for glacial geology.* The author showed that there are many similarities in processes between the subglacial deforming bed and the debrys-rich basal ice layer; however, the resultant layers will depend on the nature of the bedrock, the sediment supply and the thermal characteristics of the glacier. C. Hätterstrand presented a model of *Ribbed moraine formation.* The distribution of this type of moraine is in close connection to areas that were cold based during the ice sheets retreat; the model focuses on the processes taking place during a contraction of a frozen bed core area of an ice sheet. B.R.Rea, D. J.A. Evans & D.I. Benn dealt with *Bedrock quarrying beneath deforming bed glaciers.* The poster investigated the potential for quarrying beneath a wet-based glacier where a thin or patchy deforming till layer overlies a hard rock bed; it appeared that quarrying may be very effective in the presence of a thin or patchy deforming till in association with a well jointed/fractured hard bed rock. Y. Seliverstov dealt with the *Genesis of exaration relief.* He underlined that glacial erosion or exaration is not an effective process. As results by observations carried out in the mountains in central Asia, glaciers do not destroy, but bury some friable forming different genesis, which happened to be there. L.R. Serebryanny dealt with *Moraines of mountains glaciers: results of integrated glaciomorphological and glaciosedimentological investigations.* He maintained that the integrated glaciomorphological and glaciosedimentological approach stimulates the analysis of mechanisms of moraine formation as a result of interaction between glacier and its bed and proposed models of moraine formation for several mountain regions.

The second subsection, which groups together six posters, could be entitled «Morphological effects of Pleistocene glaciation on a regional scale». More specifically, L. Bisbal Cervello & M.A. Gil Sauri presented a poster about *Morphologic study of the Sanabria Lake (Spain).* They observed that the main effect of glacial morphogenesis, occurred during the Quaternary, on the Cantabrian mountain chain, was overexcavation, particularly of lakes; the authors examined the glyptogenetic characteristics of excavation in the lakes and gave useful parameters for further morphologic and engineering research. M. Böse dealt with *Glacial landforms in Taiwan.* The author reported evidence of Pleistocene glaciation (glacially modified valley heads and a possible lateral moraine). Owing to the island's steep relief, intense fluvial erosion and many earthflows are the dominant processes; hence, relict glacial landforms may be expected only in protected position. E. Jaurand proposed a *Comparaison de l'altitude minimale des cirques glaciaires entre les Préalpes françaises du Sud et l'Apennin septentrional.* The author observed that on the Southern French preAlps the glacial cirques were distributed from 1900 m to 2100 m, whereas on the Northern Apennines the altitudes ranged from 1350 to 1700 m; this difference, in his opinion, depends upon different types of climate during the recent Würm: dry and continental on the French mountains, wet and oceanic on the Italian chain. P. Johansson in his *Geomorphological evidences for the age of the esker chains in NE Finnish Lapland,* described some crossing esker system of various ages in the northeastern part of Finnish Lapland and determined the age relations of these systems. The youngest esker chains without a till cover were formed under the marginal zone of the receding Late-Weichselian ice sheet, while the oldest ones, clearly reworked by glacial flow, were deposited during the LateSaalian deglaciation. R.D. Khazaradze dealt with the *Old glaciation in the Caucasioni.* The author gave the different picture on times and expansion of glaciation. It was stated two-fold glaciation (Riss and Würm) and was assumed that the old glaciers of the Caucasioni were not at all so colossal as to expand to piedmont valleys. L. Menkovic & M. Markovic presented *Glacial morphology of Serbia (Yugoslavia).* They described traces of glacial forms on the mountains of Serbia such as cirques, glacial troughs, moraines produced by the Pleistocene glaciers. Positions and mutual relationships between investigated glacial forms enabled determination of the snow line altitude, which was at 1900 m on the northern sides and at 2200 m on the southers sides.

The third subsection groups eleven posters and could be entitled «Landforms and glacial morphogenesis in the Late Pleistocene and the Holocene». C. Baroni & A. Carton presented *The Adamello Group (Central Alps, Italy): geomorphological map and Holocene glacier variations.* They prepared a 1:50,000 geomorphological map of the Adamello massif, which results a very detailed representation of the changes that have taken place in the local glaciers. By numerous radiocarbon dates the authors identified Neoglacial advances between 3350-3096 and 2706-2207 years B.P., while some moraines were attributed to the Little Ice Age. A. Cesnulevicius dealt with the *Postgenetic changes of glacial relief of Lithuania.* The author gave emphasis to the large landforms of Lithuanian relief developed during the Quarternary glaciations and to the numerous geomorphological processes by which they were transformed. He underlined also that the largest area of postgenetic change was taken by erosion, termokarst, organogenic, fluvioglacial and fluvial formation. A. Coronato presented the *Late-Pleistocene Alpine-type glacierization in the Fuegina Andes, Argentina (lat 54°).* The author described the dominant erosional glacial-features and the glacial depositional systems. He identified that the ice recession would have started during the beginnings of the Late Glacial (16-14 ka B.P.) and that between 12-10 ka B.P. the equilibrium line altitude would have ascended to 600 m a.s.1., while now it is at about 1000 m a.s.l. E.A. Danilchenko gave attention to the *Morphostructures and glacial relief of a Chibagalah-Ericit zone of Cherskiy's ridge (Republic Saha).* The author considered the conditions of formation glacial relief in southeast part of Chibagalah-Ericit zone; he observed that during the maximum development of the first glaciation in Late Pleistocene more than half of the bottom of basin was blocked by glacier and that degradation of glacier was accompanied by formation of separated files of dead ice with chaotic congestion of morain hills and local depressions filled by fluvio-glacial deposits. P.R. Federici suggested *Methods of calculation of the snow limit in a mid-latitude area, the Apennines.* The author compared many methods on the Apennines chain, where glaciers became almost totally extint; he underlined that, in order to have reliable results, the various calculation methods must not applied purely mechanically, but local factors, such as exposition, contribution of avalanches, winds, topographic conformation of the basin and neotectonic influences must be taken in account. J. Jania dealt with the *Linkages between dynamics of the Hans Glacier (Spitsbergen) and morphology of its marginal zone.* He observed that the frontal part of the glacier can be divided into three dynamic zones: 1) one zone of tension flow ending down to the sea in the calving cliff; 2) a zone of compression flow of the lateral part of the glacier terminated on land; 3) narrow transition zones between the both mentioned above. A model of sediment transfer and deposition rate in particular dynamic zone is also developed. J. Mäkinen described *Sedimentation in a complex subglacial environment in Säkylä, SW-Finland.* The author gave attention to the lithofaci es and depositional history of some stratigraphic sections excavated in late Pleistocene glacigenic relieftype in SW-Finland. The study site in association with hummocky moraines respresents sedimentation within meltwater catchment area of a long tributary esker; the very complex existence of subglacial processes and related deposits is examined. M. Pelfini & C. Smiraglia dealt with *Geomorphological evidences of the recent advance of the glaciers in the Central Italian Alps.* The authors described the morphological features, mainly end and lateral moraines, left by glaciers in the main mountains groups of the Central Italian Alps during their recent advance, which moved downward for about twenty years (1965-1985), the genesis of the moraines derives mainly from dumping of supraglacial debris along the growing snow slope. R.J. Rogerson with the poster *Revisiting glacier re-advance in the Yoho Valley, B.C., Canada,* gave information about the re-advance of Emerald Glacier in British Columbia between 1978 and 1990. From 1990 the glacier has retreated, in places almost 30 m from the re-advance moraine. Both re-advance and recession are examined with reference to climatic conditions, glacier size and response time. R. Sailer & H. Kerschner proposed *a Threedimensional reconstruction of Younger Dryas glacier surface with a rasterbased GIS.* The authors, on the base of the simple topography of the valley and the well defined boundaries of the Schoeferwall glacier in the Tyrolean Alps during the Younger Dryas, which allows a detailed numeric calculation of its long profile, tried to marry the complexity of the numerical reconstruction of glacier surfaces with the possibilities of the raster--based GIS module of Arch/Info. O. S. Savoskul recognized *Holocene moraines and rock glaciers in Kamchatha, Russia,* where modern glaciation cover 874 km^2. From the features of soil development on the moraines and tephra findings, the Holocene glacial forms were divided into three age groups, formed prior to 7600-7700 yr BP (early Holocene), between 6000 and 1400-1500 yr BP (post-Hypsithermal or Neoglacial) and after 1100 yr BP (Little Ice Age, the last prominent phase of the Neoglacial advance with 14 moraines).

The fourth subsection, which could be entitled «Glacial geomorphology by means of advanced quantitative and morphometric analyses», consists of four posters.

B. Etzelmüller & J.L. Sollid in *The use of geomorphometry on glacier surfaces - Examples from Spitsbergen,* presented an integrated approach to long-term glacier analysis, considering both the surface function and its derivates. The main aim was to demonstrate how mathematical surface descriptors calculated from grid-based DEMs could be applied to classify and to quantify glacier surface changes over a period of time and to demonstrate how changing surfaces could be quantified depending on scale, accuracy and noise in the data material. The concept was tested on five Svalbard valley glaciers. I.S. Evans & N.J. Cox dealt with *Analysis, presentation and interrelation of diretional data as applied to glaciers and glacial cirques.* In this poster the use of a number of routines for circular data, available from the authors, was exemplified for data sets for whole mountain ranges specifying the aspect, position, size and form of glaciers and glacial cirques. Circular variables were related to linear variables by Fourier regression, which can be summarised by another version of the correlation coefficient. N.A. Shishonok & V.M. Yat-sukhno examined *Morphometry and genetic-age features of glacial landformes. Problems of interrelation.* They gave emphasis to the use of the morphometric method which enable one to identity its genetic, age features and hence to determine the duration of landforms transformations under the effects of later processes. The test-site was the territory of the Republic of Belarus which presents an example of classical forms of the glacial landforms; it has been found that five glaciations had covered the whole territory of Belarus from 240 000 years ago to 70 000 years ago. W. Van Huele, F. Pattyn & H. Decleir in their poster *Glacial valley form revised* proposed a general power law to describing the cross profile of a glacial valley and presented the result of systematic morphometric analysis applied to a few glaciers of the Sφr Rondane Mountains in Antarctica. The analyses also showed the importance of the morphology of postglacial processes such as post-glacial fill and slope processes on the shape of valley cross profiles.

To the fifth subsection, which could be entitled «Glacial landforms deriving from dramatic events», belongs only one poster. A.J. Russel, O. Knudsen, J.K. Maizels & P.M. Marren dealt with the *Controls on the geomorphic impact of the November 1996 jökulhlaup, Skeiðararsandur, Iceland.* The authors examined the spectacular geomorphic and sedimentary impact of the November 1996 jökulhlaup on the proximal zone of the Skeiðararsandur, Iceland. Detailed comparison of pre-and post-jökulhlaup river morphology and sedimentology allowed an assessment of the main controls on the geomorphic effectiveness of this event in a variety of different ice-marginal and proglacial settings.

Also to the sixth and last subsection, of which the title could be «Information deriving from geoecological approach», only one poster belongs. M. Pelfini, G. Strumia, A. Carminati, S. Belloni & G.C. Rossi dealt with *Response times of alpine glaciers, as defined by tree vegetation signs: the example of the Lys Glacier (Valle d'Aosta).* The purpose of the study was to calculate the response time for a sample glacier, the Lys Glacier in Valle d'Aosta, by dendrogeomorphological investigation. The curves deriving from data collected from 216 larch trees were correlated with the glacier front variation data. The maximum correlation coefficient is reached with a delay of five years between the two curves, which represents the response time of the glacier.

To sum up, the corpus of posters presented covered a large groups of topics and methodologies. The topics ranged from landform descriptions of a traditional nature, which are, however, indispensable because they represent the essential foundation for further studies, to the most advanced morphometrical and quantitative analyses. Many posters revealed a trend towards an emphasis and indepth analysis, utilizing modern methodologies, of the issue of post-glaciation remodelling on the part of various morphogenetic processes, as well as towards an emphasis on the relations between dynamic processes and the morphologic features of lanforms.