Anna Jakomulska

COMPARISON OF STRUCTURE OF MOUNTAINOUS ENVIRONMENTS OF LOCH CORUISK VALLEY (SKYE, SCOTLAND) AND THE FIVE LAKES VALLEY (THE TATRA MOUNTAINS)

INTRODUCTION

Implementation of GIS methods in environmental research enables an efficient analysis of structure of environment, which is highly labour-intensive and quite troublesome while using traditional methods. This paper presents results achieved in a research carried out in two alpine environments: The Five Lakes Valley of The Polish Tatra Mountains and Loch Coruisk Valley, Skye, Scotland, conducted with the help of GIS and statistical methods. Analysis of structures of the rehearsed environments was based on recognition of pattern of geocomplexes, which allowed for: indication of dominant and subordinate, stable and fragile geocomplexes in researched ecosystems, determination of neighbourhood of geocomplexes, comparison of frequency and strength of relationships between geocomponents in different types of geocomplexes and assessment of biodiversity of the researched environments. Landscape pattern was used for elucidating geoecological processes and prediction of further environmental changes.

SHORT CHARACTERISTICS OF AREAS OF INTEREST

The Five Lakes Valley, located in The High Tatra covers an area of about 6 km^2 while Loch Coruisk Valley in Cuillin Hills on Skye — a Scottish Island of Inner Hebrides — about 15 km^2. Both researched valleys have been modelled during the last glacial period, so in spite of different climatic, geological, hydrological, biogeographical and biocenotical conditions they have an essential common feature: an alpine relief which determines a uniform way of functioning of the environments.

The High Tatra Mountains are eroded in acidic granite which intruded in the Carboniferous period; Cuillin Hills are composed mainly of Tertian

intrusions: intermediate gabbro and ultrabasic peridotites. In humid climate granite weathers quickly producing round hills, but under climatic conditions prevailing in The Tatra Mountains it forms steep and rugged peaks. Gabbro and peridotites are extremely hard rocks and also form high and rugged peaks. Both valleys are placed within the alpine and montane zones and constitute typical glacial valleys: maximum height difference in Loch Coruisk Valley reaches 900 m and in The Five Lakes Valley — 650 m. In general, Loch Coruisk Valley is steeper, less accessible and more rugged than the latter. Both areas of interest are considered as high mountain environments and appreciated by climbing and trekking tourists.

Quaternary deposits constitute an important differentiation of both valleys. In The Five Lakes Valley they cover 73% of the researched area (moraines — 36%, slope deposits — 27% and alluviums — 10%); in Loch Coruisk Valley 67% (34%, 11% and 12% respectively). Despite the ultrabasic character or gabbro, its great resistance to weathering does not produce particularly basic soils. Generally poor soils (lithosols, regosols, rankers and podzols) prevail at both areas of interest. More fertile soils in The Five Lakes Valley developed on mylonites which formed as a result of tectonic crushes on ridge passes and in Loch Coruisk Valley — on ultrabasic peridotite and, marginally, on basic sills and dykes which cut gabbroic laccolith.

In both areas of interest surface waters are represented by alpine lakes and streams and underground waters by few moraine reservoirs and slotted waters. Due to impermeable ground, bogs and peats have developed at the very bottoms of both valleys at sites where runoff is impeded. However in more humid climate of Loch Coruisk Valley, bogs and peats dominate in the landscape while in The Five Lakes Valley they form small patches.

The most conspicuous feature differentiating the researched valleys is climate. The Tatra Mountains are placed in a moderate, transitional from atlantic to continental zone with cold winters and hot summers, precipitation peak during summer months (mean yearly precipitation reaches 1700 mm), strong foehn winds and winter inversions of temperature. Geographical situation of Skye determines its cool, extremely atlantic climate with high precipitation all over the year (yearly precipitation averages 3400 mm), strong winds and mild winters and summers leading to small temperature amplitudes (37°C, while 58°C in The Tatra Mountains). Atlantic character of Loch Coruisk Valley is further emphasised by a fact that it is located in the southern part of Skye and opens straight to the sea, allowing easy penetration of the valley by humid, westerly winds. Skye climate can be characterised by its name which derives from the Norse "skuy" meaning "cloud", in Gaelic it is Eilan á Cheo — "Isle of mists" — there are more than 300 rainy days in an average year.

The Five Lakes Valley is placed above tree line (the lowest point in the valley is The Great Lake — 1664 m a. s. l.). Loch Coruisk Valley is also devoid of trees, although it reaches sea level. This is due to hard rock, steep slopes and mainly — exposure to strong winds and humid air masses from

the sea. Main vegetation types on both areas of research are alpine meadows, grasslands and dwarf-shrub heaths, montane heaths and grasslands, fens, bogs, tall herb communities and scree and cliff communities. Some patches of subnival vegetation can be found at both sites. Both valleys have long been subjected to anthropopression (burning, tourism) and sheep grazing — its influence is depicted by introduction of anthropogenic communities and species.

METHODS

In the research, three components were acknowledged to be principal: geology, geomorphology (which determine the main processes in the ecosystem) and vegetation (which is an excellent indicator of all geocomponents). Small areas of fields of research, enormous variety of mountainous ecosystems and the aim of the research required a detailed study. Both case studies were carried out in 1 : 10 000 scale. Maps of slopes were produced by interpolation of contour maps and derivation of Digital Elevation Models. Finally slope maps were classified according to classification of mountainous relief proposed by T. Kalicki (1986). Maps of geology, slope inclination and vegetation were used for delimitation of homogenous units. Map algebra (overlaying) was carried out using simple but efficient GIS package — IDRISI. In effect a total of 40 types of geocomplexes, represented by more than 1400 individual units was created at both sites. The rank of the distinguished typological units is higher than facies but lower than *uroczyskos*. Maps of types of geocomplexes became base maps for statistical analysis of structure of the environments. Statistical methods require numerical data. Geocomplexes constitute qualitative characteristics of the environment. To quantify the data, three numerical parameters of geocomplexes were calculated: area, perimeter and number of individual land units in particular type of geocomplex. Calculation of these measurements was possible thanks to employment of GIS methods. As a result over 30 indicators were evaluated.

STATISTICAL ANALYSIS OF ENVIRONMENTAL STRUCTURE

Evaluated statistical indicators can be divided into four groups:
1. parameters of size and frequency of occurrence of land units:
   — number of delimited types of geocomplexes,
   — number of individual geocomplexes,
   — mean area of types of geocomplexes,
   — mean area of geocomplexes,
   — mean perimeter of types of geocomplexes,
   — mean perimeter of geocomplexes;
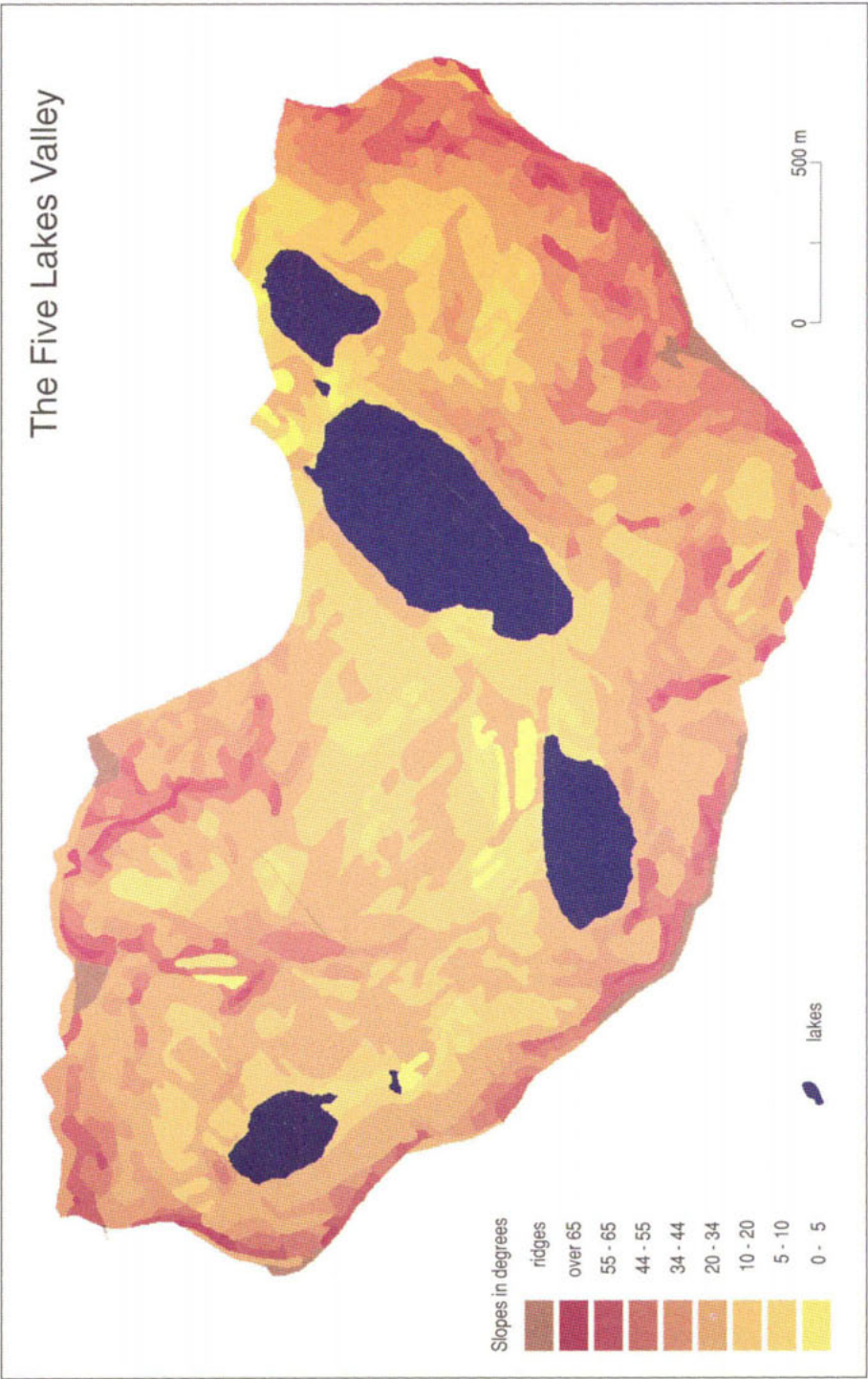2. indicators of shape of land units (Pietrzak, 1989):

The Five Lakes Valley
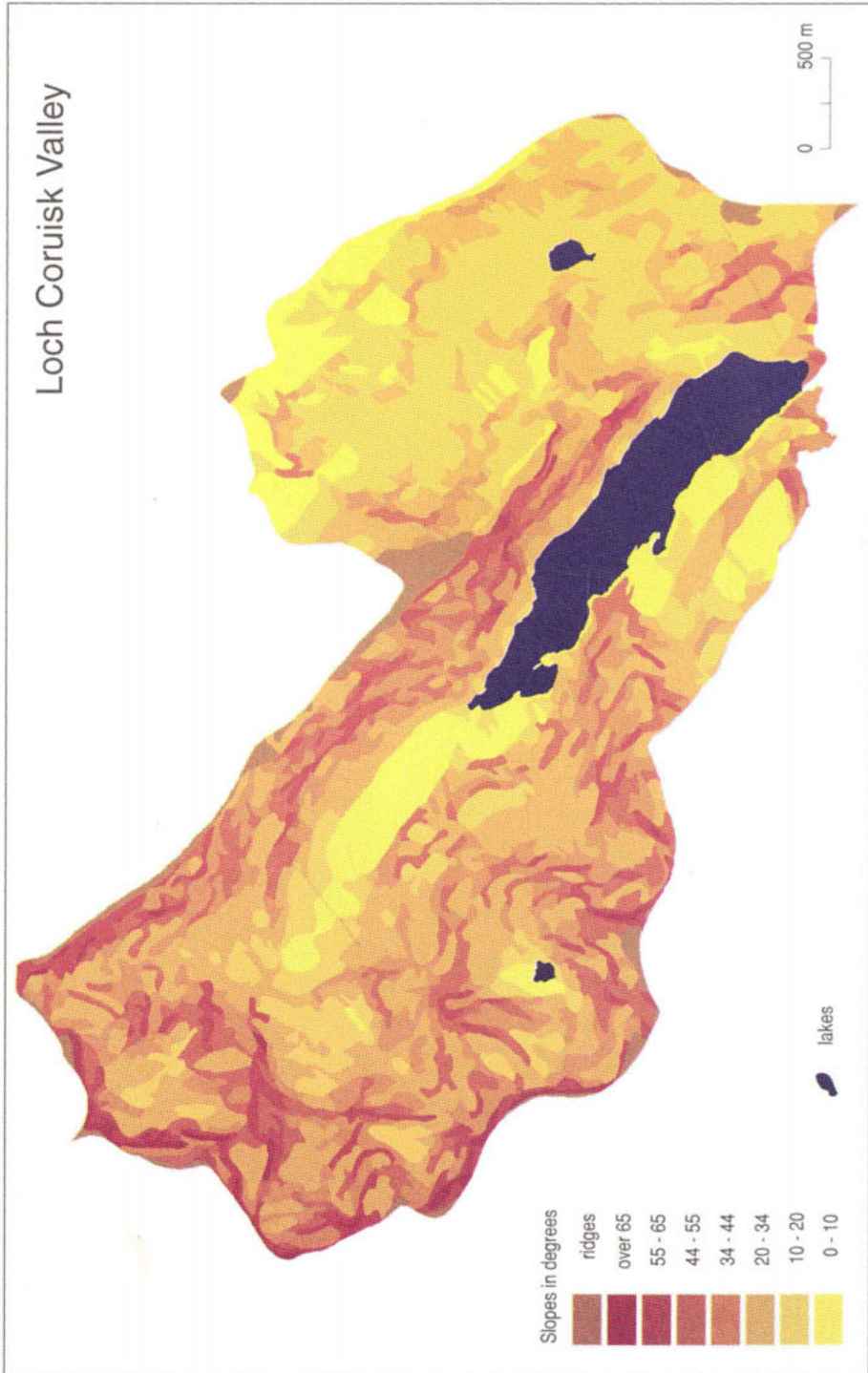
Slopes in degrees

ridges
over 65
55 - 65
44 - 55
34 - 44
20 - 34
10 - 20
5 - 10
0 - 5

lakes

0   500 m

Fig. 1a. Maps of slopes.

Fig. 1b. Maps of slopes.

The Five Lakes Valley

500 m

0

Geological units

granodiorites

chlorotised granodiorites

granodiorites with microcline

pegmatite granites with muscovite

pegmatite and aplite granites

mylonites and breccias

moraines

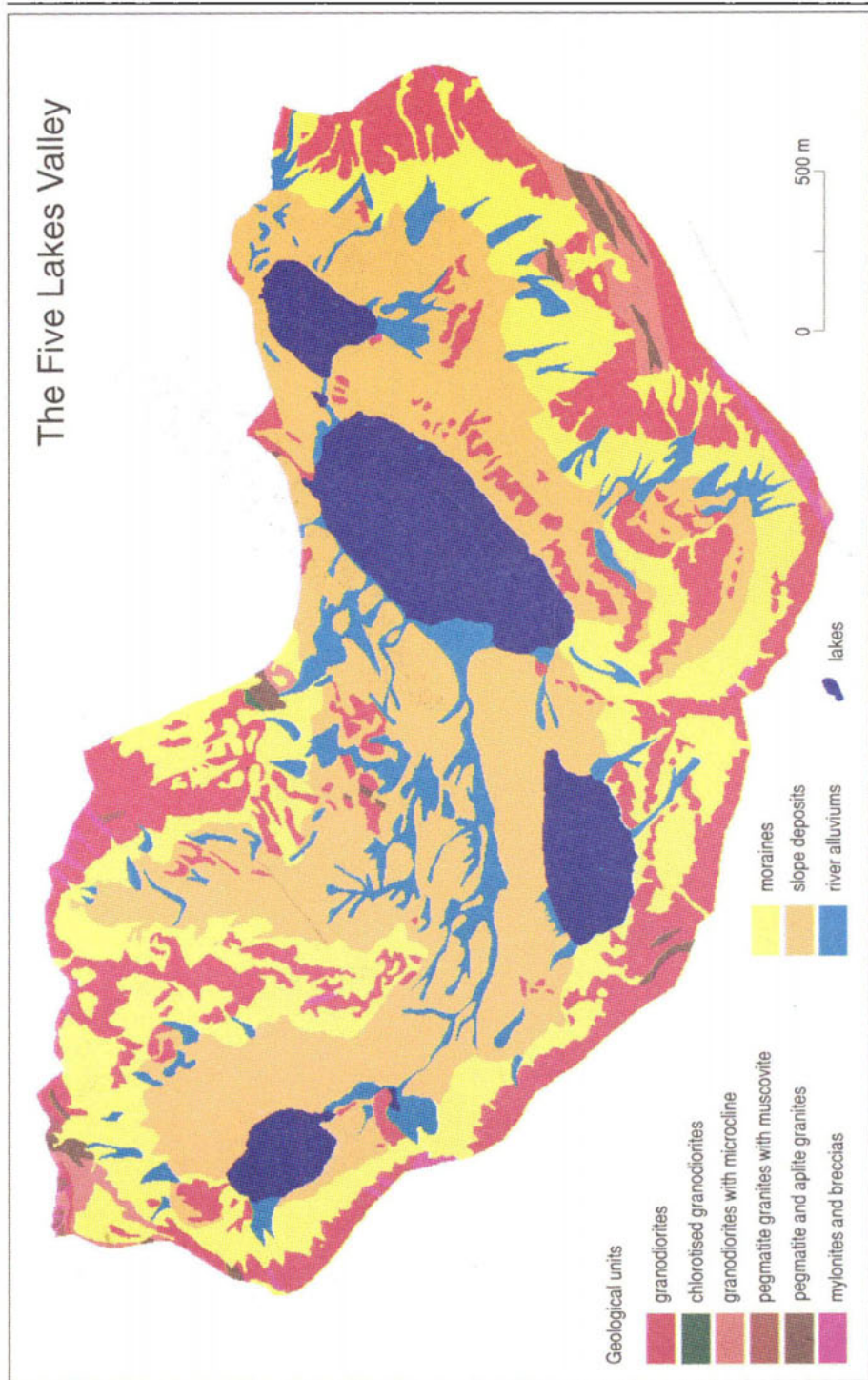slope deposits

river alluviums

lakes
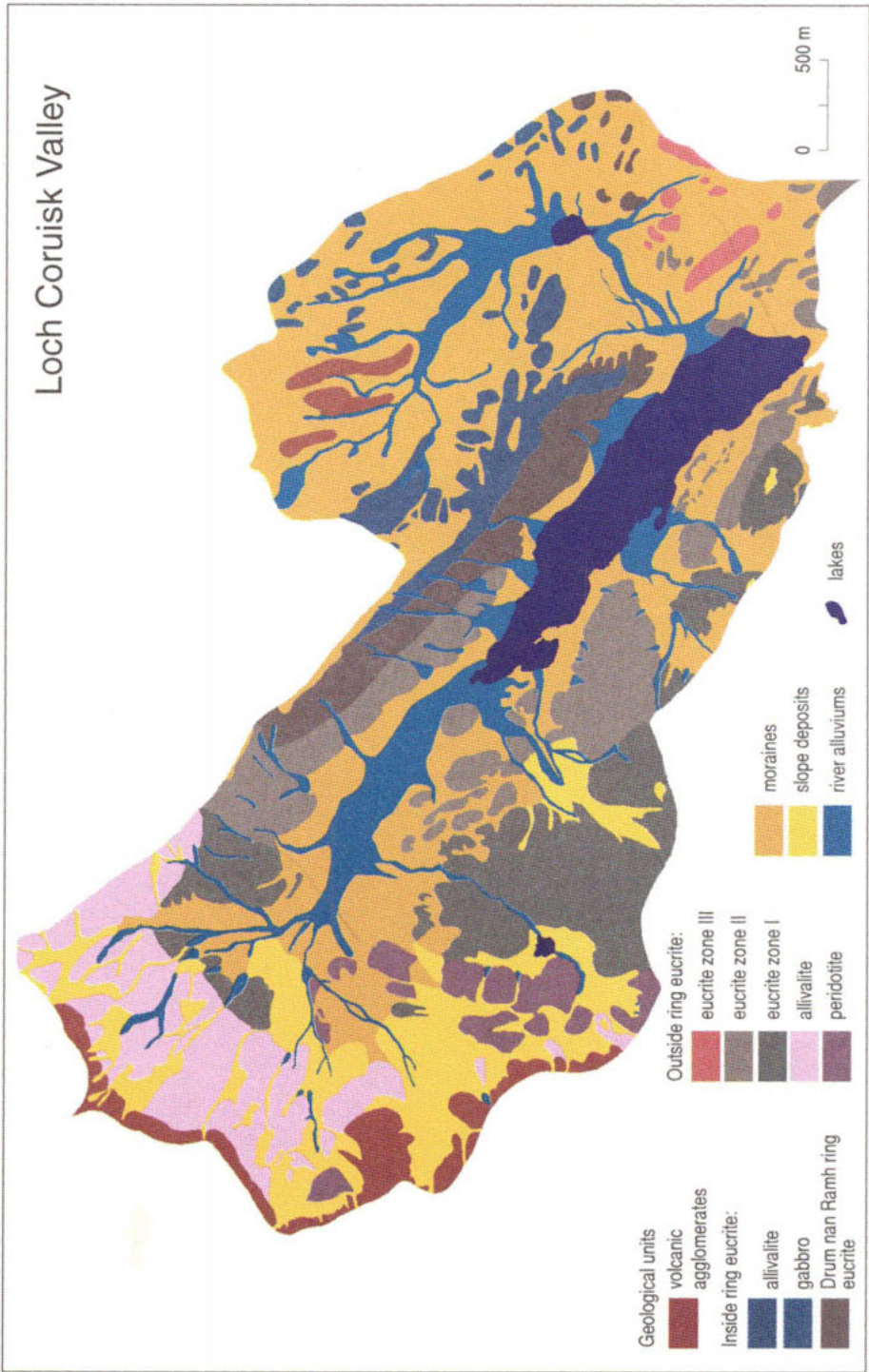
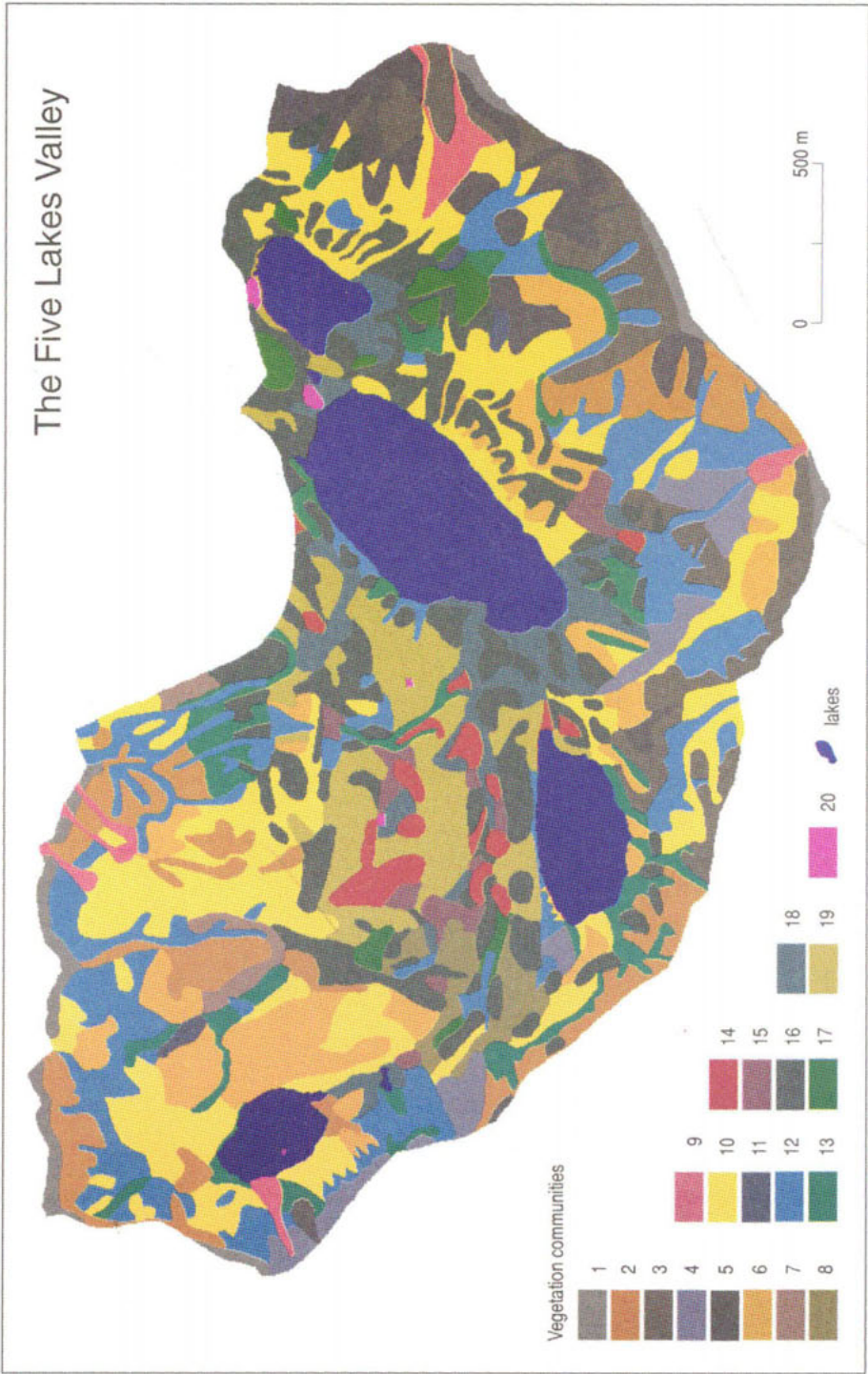Fig. 2a. Geological maps.

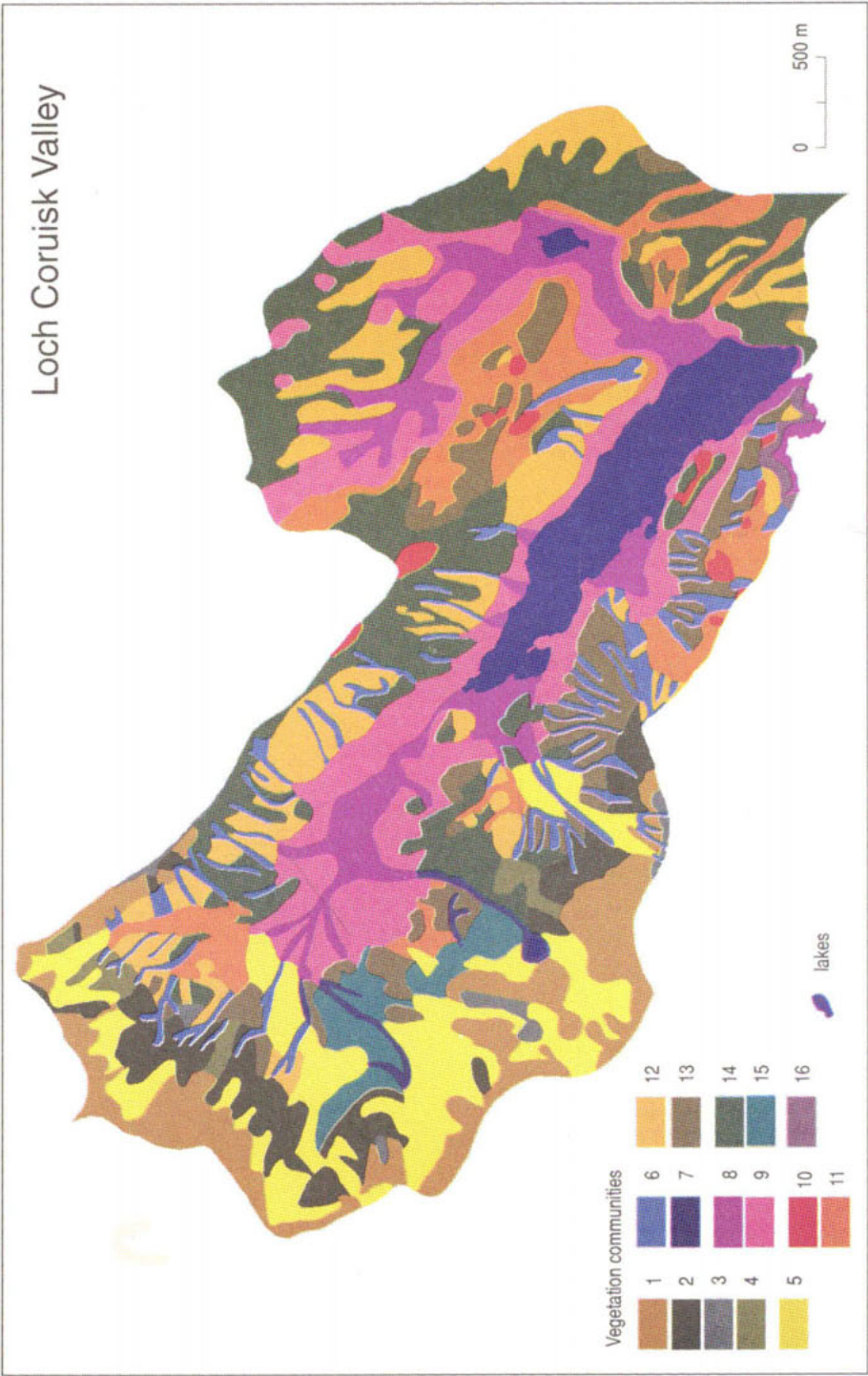Fig. 2b. Geological maps.

Fig. 3a. Vegetation maps.

Fig. 3b. Vegetation maps.

Vegetation communities of The Five Lakes Valley:

Subnival communities
1 — *Minuartio-Oreochloetum distichae*, Com. *Oreochloa disticha-Gentiana frigida, Trifido-Distichetum* subnival variant with *Oreochloa disticha*

Alpine meadows on granite
2 — *Trifido-Distichetum typicum*, 3 — *T.-D.* sphagnetosum, 4 — *T. -D.* salicetosum herbaceae, 5 — *T. -D.* salicetosum kitaibelianae, *Drepanoclado-Salicetum kitaibelianae* ,
6 — *T. -D.* scree variant with *Juncus Trifidus* , 7 — *T. -D.* caricetosum sempervirentis,
8 — *T. -D.* anthropogenic variant with *Agrostis rupestris* and *Deschampsia flexuosa*

Alpine meadows on mylonites
9 — *Festuco versicoloris-Agrostietum alpinae*, Com. with *Silene cucubalus*

Scree communities
10 — *Rhizocarpetalia*

Communities on long lasting snow cover terrain
11 — *Salicetum herbaceae* and mossy communities from *Salicetea herbaceae,*
12 — *Luzuletum spadiceae*

Tall herb communities
13 — *Calamagrostietum villosae, Aconitetum firmi, Adenostyletum alliariae*

Bogs and fens
14 — Com. with *Eriophorum vaginatum, Sphagno-Nardetum, Shagno-Caricetum*,
15 — *Caricetum fuscae subalpinum*

Dwarf-shrub heaths and shrubs
16 — *Pinetum mughi carpaticum*, 17 — *Vaccinietum myrtylli, Empetro-Vaccinietum*

Sheep-grazed communities
18 — Com. with *Deschampsia flexuosa, Hieracio alpini-Nardetum*, 19 — *Cerastio fontani-Deschampsietum*

Anthropogenic communities
20 — Com. with *Stellaria media, Urtico-Aconitetum*, Com. with *Rumex obtusifolius*, Com. with *Cardaminopsis halleri*, Com. with *Ranunculus repens*

Vegetation communities of Loch Coruisk Valley:

Alpine heaths and meadows
1 — Com. *Festuca ovina-Luzula spicata*, 2 — *Cariceto-Rhacomitretum lanuginosi*,
3 — *Rhacomitreto-Empetrum*, 4 — Com. with *Juniperus nana*

Scree communities
5 — *Rhizocarpetalia*

Tall herb communities
6 — Com. *Luzula sylvatica-Vaccinium myrtillus*, 7 — Com. *Sedum rosea-Alchemilla glabra*

Fens
8 — Com. *Carex rostrata-Scorpidium scorpioides*, Com. *Carex panicea-Campylium stellatum*, Com. *Eriophorum latifolium- Carex hostiana*, Com. with *Schoenus nigricans*,
9 — Com. *Trichophorum cespitosum-Carex panicea*, Com. *Molinia caerulea-Myrica gale*

Bogs
10 — Com. *Eriophorum angustifiolium-Sphagnum cuspidatum, Trichophoreto-Callunetum, Trichophoreto-Eriophoretum*, 11 — *Molinieto-Callunetum*

Dwarf-shrub heaths
12 — *Callunetum vulgaris*, 13 — *Vaccinieto-Callunetum hepaticosum*

Sheep-grazed communities
14 — Poor *Agrosto-Festucetum*, 15 — Rich *Agrosto-Festucetum, Alchemilleto-Agrosto-Festucetum*

Coastal communities
16 — Com. *Asplenium marinum-Grimma maritima*

— indicator of dismemberment of geocomplexes: $F = \dfrac{P}{2\sqrt{\Pi A}}$,

— indicator of roundness of geocomplexes: $R_c = 4\Pi\dfrac{A}{P^2}$,[where A — area of individual geocomplex, P — perimeter of individual geocomplex],

3. measures characterising spatial (horizontal) structure of geocomplexes:

— absolute entropy: $E = \sum\limits_{i=1}^{n} p_i \log_2 p_i$[where: $p_i = \dfrac{s_i}{s}$ — probability of occurrence of particular state (the proportion of landscape in habitat i or % of geocomplexes within the whole researched area), s_i — area of individual geocomplex within a type (or 1), s — total area of a type (or number of individual units within a type), n — number of observed individual units within a type], (Richling, 1992),

— relative entropy: $E_w = \dfrac{E}{E_{\max}}$ [where: $E_{\max} = \log_2 n$], (Richling, 1992),

— dominance: $D = E_{\max} - E$ (Turner, 1989),
— indicator of landscape unity $I = 1 - E_w$, (Szajnowska, 1978),

— indicator of heterogeneity $\left[K_n = \dfrac{\sum\limits_{i=1}^{i=n-1}\sum\limits_{j=i+1}^{j=n} m_i m_j}{C_n^2} \right.$, where

$C_n^2 = \dfrac{n(n-1)}{2}$, n — number of types of geocomplexes, $m_i = \dfrac{s_i}{s}$, s_i — area of types of geocomplexes, s — total area of the valley],

— indicator of likelihood (frequency of the nearest neighbour): $P = 2\dfrac{c}{a+b} \cdot 100\%$ [where: $a(b)$ — total length of border of unit a (and b respectively), c — total common length of border between units a and b], (Richling, 1992);

4. measures characterising relationships between different features of geo-components:

— indicator of strength of relationships between geocomponents: $W = \dfrac{P_{rg}}{P_g}$ when $P_g < P_r$ and $W = \dfrac{P_{rg}}{P_r}$ when $P_g < P_r$, [where: P_{rg} — area or frequency of types of geocomplexes with r type of vegetation and g category of geology, P_r — total area (or frequency) of geocomplexes with r type of vegetation, P_g — total area (or frequency) of geo-complexes with g category of geology], (Richling, 1992; Bezkowska, 1986);

— Pearson's indicator of relationship $P = \sqrt{\dfrac{\Sigma\left[\dfrac{\Sigma' / n_2}{n_1}\right] - 1}{(r_1 - 1)(r_2 - 1)}}$, where:

r_1, r_2 — number of categories of the first and second component, f — number of connections between analysed components (or area of types of geocomplexes with two features of the components), n_1, n_2 — total number of classes with the first or the second feature (or area of types of geocomplexes with the first or the second feature of the components)], (Aleksandrowa, 1975).

For comparison, where possible, indicators were calculated both on the base of areas and number of geocomplexes within a type. Additionally, for some of the indicators characterising size and shape geocomplexes, an index of variability for each type of geocomplex was calculated: $V = \dfrac{s}{\bar{x}} \cdot 100\%$ [where: s — standard deviation of area within geocomplex type, $\bar{x}$ — mean value of area within geocomplex type], (Bočarov, 1976). Specification of the means of the evaluated values of indicators for each geocomplex type for the Five Lakes Valley and Loch Coruisk Valley is presented in Table 1 (all values of measured indexes and parameters are given in: Kurnatowska, 1995).

Table 1

Mean values of indicators	The Five Lakes Valley	Loch Coruisk Valley
Number of delimited types of geocomplexes	42	41
Number of individual geocomplexes	1407	1442
Total researched area (sq. meters)	5 823 934,33	14 944 730,10
Total researched area without lake areas (sq. meters)	5 200 148,63	14 023 622,32
Mean area of types of geocomplexes (sq. meters)	123 813,06	342 039,57
Mean area of geocomplexes (sq. meters)	3 695,91	9 725,12
Mean perimeter of types of geocomplexes (meters)	12 162,40	20 468,14
Mean perimeter of geocomplexes (meters)	363,06	581,96
Indicator of area variation	210	285
Indicator of perimeter variation	126	162
Indicator of dismemberment of geocomplexes (WRK)	1,91	2,18
Indicator of WRK variation	29	33
Indicator of roundness of geocomplexes (WK)	0,33	0,27
Indicator of WK variation	42	52
Indicator of strength of relationships between geocomponents based on areas	0,46	0,40
Indicator of strength of relationships between geocomponents based on frequencies	0,48	0,38
Absolute entropy based on areas	5,26	4,73

Mean values of indicators	The Five Lakes Valley	Loch Coruisk Valley
Absolute entropy based on frequencies	5,00	4,84
Relative entropy based on areas	0,97	0,88
Relative entropy based on frequencies	0,93	0,90
Indicator of landscape unity based on areas	0,024	0,116
Indicator of landscape unity based on frequencies	0,072	0,095
Dominance based on areas	0,13	0,62
Dominance based on frequencies	0,39	0,51
Indicator of heterogeneity	0,9797	0,9646
Pearson's indicator of relationship based on areas	0,0128	0,0196
Pearson's indicator of relationship on frequencies	0,0136	0,0196
Mean indicator of likelihood (frequency of the nearest neighbour)	3,92	5,03

INTERPRETATION OF RESULTS — COMPARISON
OF THE RESEARCHED ALPINE VALLEYS

The leading component, determining character of all other components in alpine environments is relief. Strong dependence on gravitation is expressed by elongated and strongly dismembered shapes of geocomplexes. The most elongated shapes are characteristic for geocomplexes which are under strongest influence of slope processes and water flow (geocomplexes of subnival and alpine zone and hydrogenic ones). At the same time these geocomplexes are least transformed by man and are characterised by high cohesion.

At both sites enormous diversity of environments was recognised (strong break up and dispersion of types of geocomplexes). High diversity of small areas is typical for alpine environments and results from a wide range of different scale factors e.g.: macro-, meso- and microclimate. However, diversity of the researched areas can be attributed to different factors. In The Five Lakes Valley the main factors differentiating vegetation and hence landscape are: height above sea level (climatic zoning) and meso- and micro-relief (slope inclination and aspect) which determine soil humidity and microclimate. In Loch Coruisk Valley extremely humid climate reduces influence of temperature and sun exposition and emphasises significance of slope exposure to humid air masses and strong winds. The effect of these humid conditions is blurring of the outlines of vertical climatic zoning: lack of trees within forest zone, lowering of communities typical for alpine zone as low as to the sea level, and in the conditions of low competition, descent of some alpine species to the bottom of the valley. Main factors influencing the researched landscapes are reflected in a wide range of typical vegetation communities: alpine meadows in The Five Lakes Valley and bogs and fens in Loch Coruisk Valley (see included maps). Geocomplexes with these communities constitute dominant geocomplexes in the researched land-

scapes, and, being climax communities, are characterised by high cohesion and stability.

An interesting differentiation of the researched environments is differentiation of geology. Geocomplexes on basic geological formations (mylonites in The Tatra Mountains and peridotites on Skye) are unique and conspicuous in the landscape because of their proliferating basic flora dominated by herbal species with big flowers. Because both mylonites and peridotites are easily weathered, basic communities are endangered by degradation. This fact should be taken into account while planning tourist routes. Unfortunately, nearly all the basal habitats in The Five Lakes Valley are on the mountain passes, which are crossed by tourist routes. These areas are hence subject to strong tourist and water erosion. In The Five Lakes Valley a classic example of an alluvial cone cut by a deep and still widening corrasion gully, trampled by tourists can be observed.

Of main importance to landscape diversity are also geocomplexes of small area frequencies but large quantity frequencies (many small units within one type of geocomplex), which cut large, 'background' geocomplexes. These are mostly represented by geocomplexes with hydrophillic communities on river alluviums. Because of small areas their cohesity is low which means that they are fragile to slightest changes of any of the environmental factors determining their habitats.

One of the most important conclusions achieved in this part of research was confirmation of the fact, that detailed phytosociological studies can replace complex environmental research. This is due to the fact, that vegetation is a perfect indicator of all environmental characteristics of the habitat like geology, geomorphology, hydrology and microclimate. Abrupt discontinuities in vegetation are associated with abrupt discontinuities in the physical environment and vegetation patterns in space reflect general pattern of the landscape and can lead to general conclusions concerning ecological processes. This is a not a new conclusion but its confirmation is important, as in mountain environments detailed studies of microclimate or hydrology are hardly feasible. Detailed studies of vegetation, being comparatively easy method of research, can be considered as the most important method of research in so diversified ecosystems.

In spite of alpine character and low accessibility of the areas of research, both polygons have been subjected to anthropopression for many years. Sheep grazing and burning of shrub communities led to significant changes of environmental structure in both valleys. The most transformed areas in the Five Lakes Valley are montane zone and lower parts of alpine zone, where shrub and heath communities were replaced by meadow and sometimes even mossy communities. In Loch Coruisk Valley montane communities stretched down to forest climatic zone. Because of low competition even some montane species descended to lower parts of the valley. On both polygons man's activity led not only to disturbance of natural sequence of vegetation communities but also to unification of structure of montane

zones. These parts of both valleys are less diversified; with large and cohesive geocomplexes. Apart from changes in proportion of natural communities, some of the communities are inhabited by lowland species, alien to the researched areas. Abandonment of burning and sheep grazing (establishment of National Park in the Tatra Mountains, and gradual climate cooling on Skye) led to gradual withdrawal of lowland and anthropogenic species. However, natural succession may last many years — in extreme cases natural communities may not return at all. For example heather encroachment in Scotland leads to soil acidification and in some cases to development of peat processes. In the Tatra Mountains grazed meadow communities form compacted sod where dwarf mountain pine (*Pinetum mughi carpaticum*) seedlings can not cut-trough. In these cases anthropogenic changes to environment are irreversible and lead not only to evident changes of real vegetation but also to permanent changes of habitats which in long run lead to changes of potential vegetation. Stability of geocomplexes with anthropogenic vegetation is confirmed by high values of indicators of strength between geocomponents.

Summarising, it can be concluded that subnival, alpine and low, hydrogenic parts of both valleys are characterised by strong diversity and dispersion of landscape, with long individual geocomplexes and strong relationships between geocomponents (cohesive and stable). Montane zone, being a transitional zone between alpine and forest zones includes many geocomplexes which are characteristic for both zones. As many communities reach their extreme habitats, higher diversity and lower stability of montane zone should be expected. Meanwhile, significant reduction of landscape diversity (large, cohesive geocomplexes) and strong relationships between geocomponents are observed. This is an evident result of intensive and long-term anthropopression. This fact confirms also a long acknowledged fact that slight, short-term human activity leads to landscape variation (for instance tourist routes), while strong and long-term activity leads to unification of landscapes.

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