IAG

European Regional Geomorphological Conference

HUNGARY

April 9 - 12, 1996

PLENARY PAPERS

GEOMORPHOLOGY AND THE
CHANGING ENVIRONMENT
IN EUROPE

GEOMORPHOLOGY AND THE CHANGING ENVIRONMENT IN EUROPE

EUROPEAN REGIONAL CONFERENCE
organised by the
INTERNATIONAL ASSOCIATION OF GEOMORPHOLOGISTS
(IAG)

Hungarian Academy of Sciences
Budapest, 9 April, 1996

Plenary papers

edited by

Dénes Lóczy

Budapest
1996

Published and copyright by the
Geographical Research Institute
Hungarian Academy of Sciences
Budapest

ISBN 963 7395 72 5

Printed by
CIER PRINT Bt. Budapest

Evolution of Surfaces of Planation Controlled by Tectonic and Erosion/Accumulation Cycles:

A Model for the Geomorphological Evolution of the Transdanubian Mountains, Western Hungary

PÉCSI, Márton
Geographical Research Institute, Hungarian Academy of Sciences
P.O.B. 64 H-1388 Budapest, Hungary

Abstract

This model claims that the surfaces of planation once produced by some erosional processes, were reshaped in the later geological periods by repeated, alternating erosional and accumulation processes on the morphostructure also repeatedly affected by tectonic uplift, subsidence and horizontal displacement.

According to this model, late Mesozoic tropical etchplanation with paleokarst and bauxite formation did not continue during the Tertiary in the Transdanubian Mountains of Hungary. As a consequence of multiple differential tectonic subsidence, most of the range was buried in various thickness and at various intervals. This *burial* was followed by complete or partial exhumation on at least three occasions (Paleogene, Neogene and Quaternary). During repeated burial and exhumation the Cretaceous tropical etchplain was affected by further erosion or accumulation through non-tropical processes (such as peripedimentation, marine terrace formation, alluvial fan building and others). In the horst series of the Transdanubian Mountains, divided by graben-like basins, the position and evolution of the geomorphological surfaces allows the identification of some main groups:

1. (semi)exhumed horst of etchplanation in summit position;
2. buried horst of etchplanation in uplifted position;
3. horst of etchplanation in threshold position, buried or exhumed and reshaped, mostly pedimented;
4. buried etchplain in basin position;
5. peripediments, rock pediments, locally buried under detritus.

The model of geomorphic surface evolution through alternating erosion/accumulation does not only apply to the Hungarian medium-height mountains, but also to

numerous other geomorphological regions, eg. the Alpine-Carpathian-Dinaric Mountains, several old mountains and massifs of Europe and other continents.

Introduction

The term *geomorphological surfaces* denotes plains and gently sloping slopes, which are the products of erosion, of accumulation or of their combination, under the influence of tectonic processes. Their formation may be dated from their correlative sediments or by other methods.

For the timing of successive formation of landforms, ie. for a *reconstruction of the denudational chronology,* an interpretation of the different geomorphological surfaces is needed. Several models were proposed for the development of erosional surfaces (landforms) on great continental morphostructures. Some of these have become classic (DAVIS, W. M. 1906, 1922; PENCK, W. 1924; KING, L. C. 1949, 1962; BÜDEL, J. 1957 and his followers, BULLA, B. 1958; BREMER, H. 1986).

1. According to DAVIS, the *peneplain* (ultimate peneplain) is the final product of fluvial erosion on different humid regions. The *almost plane surface* is the penultimate phase of the planation at the base level.
2. PENCK's Primärrumpf (primary peneplain) is a plain surface just emerged above the sea level. *Piedmonttreppen* (piedmont benchlands) are explained by fluvial erosion and retreat of valley sides. Erosional surfaces on slowly but uniformly elevating morphostructures may be explained this way.
3. According to KING, pediplanation also takes place by the retreat of slopes on slowly but continuously elevating terrains, especially under semiarid climates, where the rate of the mechanical weathering exceeds that of the chemical one. Retreat of slopes results in a gradual surface lowering and pediplain formation. According to KING, pediplanation is the most widespread process reducing relief, this way it replaces DAVIS' peneplain theory.
4. BÜDEL proposes that the *double etchplain* (doppelte Einebnungsfläche) is an erosion surface created by intensive lateritic deep weathering and strong washdown (stripping) of the thick weathered rock under a seasonal dry and wet tropical climate.
5. A *pediment* is a gentle erosional foothill slope in front of a steep mountain slope, generally formed of hard rock. *Pedimentation* is admitted to be the most general erosional, planation process. McGEE, W. J. (1897) believes that a river, on leaving a mountain, deposits most of its load, while the rest of the sediment transported causes lateral planation (corrasion). The pediment is covered by a thin layer of sediment, deposited by sheetwash or by small rivers under a semiarid climate.

Several researchers adhere to the above models for the origin of *surfaces of planation*, while others criticise or modify them. In one respect these models are uniform, they suppose that the studied surfaces were formed during *long geological times*, when uplift was slow, continuous or periodical. It is generally admitted that the highest situated geomorphological surfaces are the oldest, the lower ones are ever younger. Such presumptions might only be valid for a part of the cases and for some geological times.

Presumably the planation surfaces (models 1 to 5), explained by different processes, might be attributed to effects of as many different geographical environments. If this is true, each of these models and conceptions generally represent genetically and climatologically different morphofacies rather than one single, global type of surface. It must be mentioned that these early models of planation surfaces were based on *fixist tectonism.*

In this presentation we want to introduce a *polygenetic model of geomorphological surface evolution*, through processes acting on different morphostructures affected by plate tectonic events, particularly in orogenic belts. The units studied were horizontally displaced over great distances, tectonically dismembered, recurrently uplifted and subsided, thus the planation surface became repeatedly buried, elevated and exhumed again (PÉCSI, M. 1970a,b).

Polygenetic *morphostructures with planation surfaces*, which were shaped under the influence of alternating *erosional and depositional* processes of long duration, were removed from their original place and carried over long distances, passing under various climatic belts. This way units of most different genesis might have come in each other's proximity.

The tectonic and geomorphic history of the Transdanubian Mountains (western Hungary) was used as a model for the evolution of such polygenetic planation geomorphological surfaces. Geological and geomorphological studies of the last half century served as a basis of a new geomorphological evolutionary model, differing from the previously mentioned ones (PÉCSI, M. 1968, 1975, 1993; SZÉKELY, A. 1972).

Discussion

The Transdanubian Mountains (TM) is a low range of slightly folded structure, built mainly of Mesozoic and Paleogene carbonates (limestone and dolomite), affected by overthrusts and faults. Horst and graben structures are common, delimited by mainly NE-SW and NW-SE running structural lines. In the southern foreland a thick Paleozoic sequence of south Alpine affinities underlies the similarly thick Mesozoic strata *(Fig. 1).*

Comparative structural investigations proved that the TM was a part of the carbonate platform formed at the northern margin of the African plate in the southern Tethys, during the Triassic. During the rifting and subsequent convergence of the Tethys this unit was overthrusted on an oceanic crust fragment, the Penninic unit. The TM, as a part of a microcontinent, was subsequently carried into the southern Alpine area, wherefrom, in late Cretaceous/Paleogene times it was horizontally shifted into the Carpathian basin (HORVÁTH, F. 1974; GÉCZY, B. 1974; WEIN, GY. 1977, 1978; BALLA, Z. 1988, HÁMOR, G. 1989; FÜLÖP, J. 1989; STEGENA, L. and HORVÁTH, F. 1978).

During the *late Triassic* and *early Jurassic* the low and extended *carbonate platform* of the TM was cut into a horst and graben structure. In the grabens the sedimentation went on during the Jurassic and early Cretaceous. On the elevated parts a long lasting continental downwearing went on during the Jurassic and Cretaceous. The upper Triassic carbonates were affected by tropical karstification, accompanied by bauxite formation. Cockpits and tower karst may have been formed under tropical savanna climate with humid and dry seasons, simultaneously with bauxite formation. The initial sediments of the bauxite formation were resedimented from siliciclastic areas by sheet wash and by small rivers. Lateritification was simultaneous with karstic planation. Witnesses of this *marked tropical karst planation* were buried and preserved by lower Cretaceous (Albian), upper Cretaceous, and, locally, Paleogene sediments in the TM.

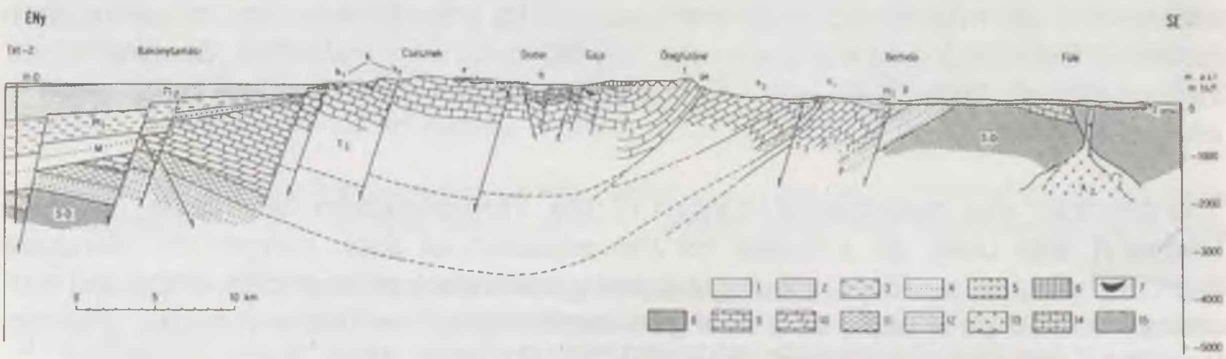

Fig. 1 Profile across the Bakony Mountains (after WEIN, Gy. and PÉCSI, M.)
1 = Holocene-Pleistocene fluvial sand and gravel, alluvial plain; 2 = Upper Pannonian sand and clay; 3 = Lower Pannonian (Miocene) claymarls; 4 = Lower Miocene-Upper Oligocene gravel and sand (in the Dudar Basin); 5 = Eocene coal seams and carbonate rocks; 6 = Lower Cretaceous (Aptian, Albian and Cenomanian) limestones and calcareous marls; 7 = bauxite and related formations; 8 = Jurassic limestones; 9 = Upper Triassic dolomites and limestones; 10 = Middle Triassic limestone; 11 = Lower Triassic siltsstone, marl and limestone; 12 = Permian sandstones and conglomerates; 13 = Upper Carboniferous granite porphyry; 14 = Lower Carboniferous conglomerate and shale; 15 = Silurian - Devonian phyllite and marble; t = uplifted remnant of tropical etchplain; ft = buried etchplain; e = exhumed etchplain, locally covered with Miocene gravel; pe = mountain margin benchland; h_2 = Pannonian marine terrace; h_1 = piedmont surface (pediment); g = Pleistocene piedmont surface formed on moderately consolidated sediments (glacis); k = remodelled tropical etchplain in threshold position; Tét-2 = prospect drilling; S-D = Silurian-Devonian; T_1,T_2,T_3,= Lower, Middle, Upper Triassic; M= Miocene; Pl_1 = Lower Pannonian (Upper Miocene); Pl_2 = Upper Pannonian (Upper Miocene);

Buried surfaces of karstic planation may be found between horsts, forelands and on horsts, buried with Cretaceous or Tertiary strata *(Figs. 2* and *3)*.

The tropical *karst planation surface* of the TM was slightly *remodelled* between the late Cretaceous and middle Eocene (Laramian tectonic phase?). On horsts summits it was well preserved, but on the margins pediments were formed due to early Eocene subarid coarse clast production. Dolomite karst towers and bauxites, if not buried, were eroded or resedimented.

During middle and late Eocene the area of the TM became an archipelago. Most of its territory subsided continuously, but not uniformly. The sea inundated the low horsts and intramontane basins. Bauxite bearing karstic surfaces of etchplanation were often buried during the Eocene.

Bauxite lenses in sinkholes, capped with Eocene layers, are often interpreted as a result of a continuation of tower-karst plain formation and bauxite genesis in the first part of the Eocene (BÁRDOSSY, Gy. 1977; MINDSZENTY, A. *et al.* 1984). This would mean that such bauxites are not merely products of Eocene redeposition of earlier deposits. We think, however, that early Eocene conditions characterised by dolomite breccia formation were not favourable for bauxite genesis and tower karst

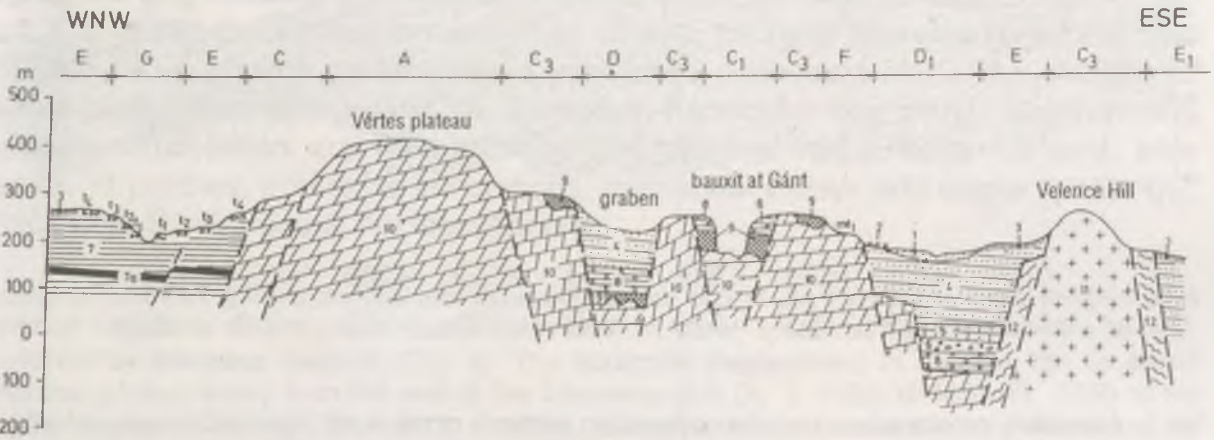

Fig. 2 Geomorphological surfaces in the Vértes Mountains in Hungary
A = exhumed horst in summit position, a remnant of slightly remodelled Cretaceous etchplain; C = horst in foothill position; C_1 = totally buried; C_3 = totally exhumed; D= buried surface of etchplain in intermontane graben position; D_1 = intermontane graben, filled with molasse and alluvial fans; E = glacis d'erosion with terraces; E_1 = rock pediment and glacis d'erosion; F = remnants of marine terrace (Upper Pannonian); G = submontane basin with river and glacis terraces; t_1-t_4= fluvial terraces; mt_1 = marine terrace; 1 = alluvium and meadow soil; 2 = alluvial fan; 3 = loess and loess-like sediments; 4 = Pannonian sandy and silty formations; 5 = Sarmatian formations; 6 = Miocene gravel and sand; 7 = Oligocene sand and clay formations; 7a = Oligocene lignite; 8 = Eocene limestone; 9 = Cretaceous bauxite; 10 = Triassic dolomite and limestone; 11 granite; 12= Carboniferous metamorphic rocks

evolution. Under a subaridic climate predominantly coarse clastics were formed and transported by ephemeral water-courses and pedimentation prevailed (PÉCSI, M. 1965, 1970b).

From the Eocene-Oligocene boundary the TM was uplifted and the previously submerged and buried parts were eroded. Some segments or entire horsts were exhumed and subsequently pedimented. There are several horsts, where bauxite and tropical tower-karstic surfaces were preserved under a thick Eocene limestone cover *(Fig. 3)*.

During the second part of the Oligocene the horizontal shift of the TM was going on, its subsidence was highly differentiated. This is supported by the fact that sediments of differing facies (coarse clasts, gravel, sand and clay) were deposited on the surface of the TM, which moved eastward. The sediments originating from some higher, crystalline mountains in the vicinity.

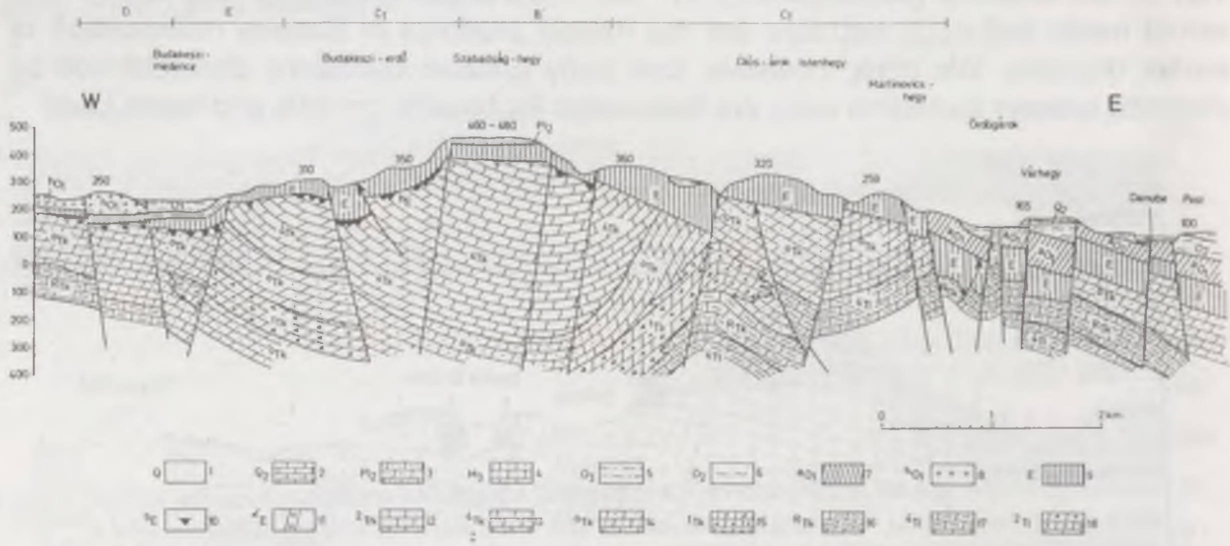

Fig. 3 Alternating erosional/accumulational planation surfaces of the Buda Highland in Hungary (after PÉCSI, M. and WEIN, Gy.
A = exhumed, planated surface in uplifted position; B = buried Cretaceous etchplain in uplifted position; C = surfaces of planation in uplifted position: 1) totally buried, 2) partially exhumed, 3) totally exhumed; D = buried surfaces of planation in graben position; E = glacis d'erosion; 1 = Pleistocene loess and wind blown sand; 2 = Pleistocene travertine; 3 = Pliocene sand, clay, travertine; 4 = Sarmatian conglomerate. and limestone; 5 = Upper Oligocene sandy clay, silt; 6 = Middle Oligocene clay; 7 = Lower Oligocene marl; 8 = Lower Oligocene sandstone; 9 = Eocene formations; 10 = Eocene reworked bauxite and conglomerate; 11 = Eocene acid dyke; 12 = Upper Triassic Dachstein Limestone; 13 = Upper Triassic Hauptdolomite; 14 = Upper Triassic coarse dolomite; 15 = Upper Triassic cherty dolomite; 16 = Upper Triassic marl, limestone, dolomite; 17 = Middle Triassic pink dolomite; 18 = Middle Triassic *Diplopora*-bearing dolomite

During the Miocene (from 24 to 5.5 Ma) the relief of the TM and its close environs changed repeatedly and fundamentally in consequent tectogenetic phases, horizontal and vertical displacements, subduction, a powerful volcanic activity, partial transgressions and regressions. These processes resulted in a *geomorphological inversion* at the end of the Miocene. The Mountains was uplifted to a moderate altitude, but definitely over its surroundings, for the first time during the Tertiary. On its sinking north-eastern part andesitic volcanoes erupted during the middle Miocene (15-14 Ma BP). Deposition of terrestrial gravel and other clastics continued on the margins of planation surfaces, with some interruptions.

On some low-lying Mesozoic horsts and in intramountain small basins the remnants of etchplains were newly but incompletely buried during the late Tertiary. On tectonically uplifting horsts the old tropical karsts were exhumed and remodelled.

During the late Miocene by the *Sarmatian and Pannonian transgression* (ca 13 to 11 Ma BP) the TM subsided again, but adjacent regions to the south and north (Little Plain and Transdanubian Hills) were subsided at higher rate thus the TM remained a mainland or an archipelago (JÁMBOR, Á. 1989). *Some mountain groups, marginal horsts and intramountain grabens were buried, in fact, for the third or fourth time* during the Tertiary, under Pannonian sands and freshwater limestones, at an elevation close to the base level.

During the late Miocene the majority of horsts in the TM were at an elevation of 100 to 200 m above the Pannonian lake level. Due to the uplift and *climate turning from subhumid to semiarid,* pedimentation processes intensified along the margins of horsts for short periods (eg. at the Sarmatian-Pannonian boundary). Morphological evidence of deflation are wind-abraded and polished rocks, sand blankets, iron-varnished pebbles, iron-oxide concretions, meridional valleys and ridges (yardangs), which were formed during the late Miocene.

Horsts uplifted during such periods and especially at the end of the Pannonian were stripped off a cover of Oligocene and Miocene clastic sediments. In some spots marine shelves were formed, preserved by travertine deposits *(Fig. 4)*. The horizontal displacement of the TM into its recent structural position lasted from the end of the Oligocene (BÁLDI, T. 1982; HÁMOR G. 1989) to the middle Miocene (12-10 Ma BP, BALLA, Z. 1988, KÁZMÉR, M. 1984), when the subsidence of the Pannonian basin started. From about this time tectogenetic processes caused repeated subsidence and uplift of the horst groups and grabens of the TM, upward movements dominated. This resulted in formation of marine terraces, deltaic deposits and erosional foothill slopes on marginal parts of the mountains.

At the *beginning of the Pliocene* (5.4 Ma BP) uplift intensified. From the late Miocene on the climate shifted to a subhumid one. In consequence, a considerable part of the Tertiary siliciclastic, gravel, sand cover of the TM was eroded and redeposited on the forelands. On the unconsolidated molasse like sediments a broad hillfoot surface took shape, while in the forelands wide alluvial fans were deposited. The hot subarid climate was interrupted several times and followed by subhumid warm periods. This increasingly favoured the cyclic development of red and variegated clays.

Neither the considerable time span of variegated and red clay formation nor the cause of the subhumid climate has been investigated in details. The effect of these events on the morphological evolution also needs further studies.

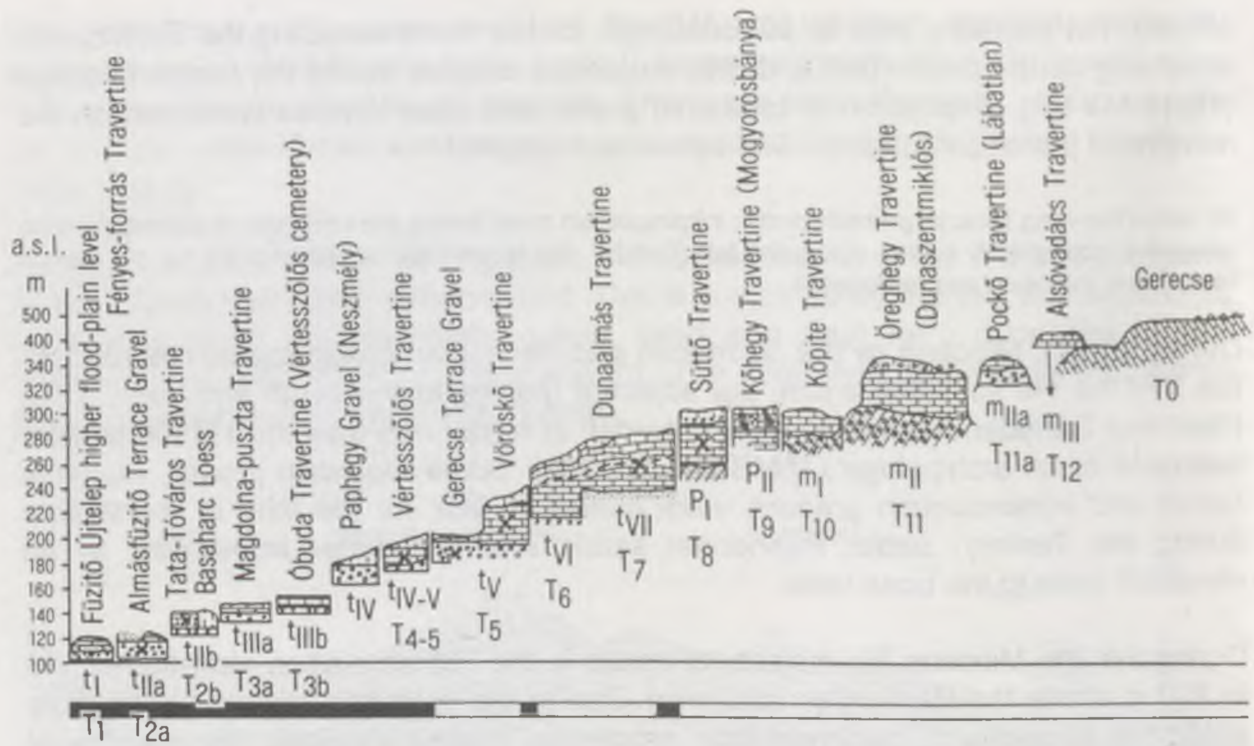

Fig. 4 Geomorphological surfaces and travertine horizons in the Gerecse foreland (PÉCSI, M., SCHEUER, Gy. and SCHWEITZER, F. 1988)
t_I-t_{VII} = river terraces usually covered by travertines (T_1-T_7) and loess; P_I-P_{II} = Pliocene pediment surfaces covered by travertines (T_8-T_9); m_I-m_{III} = Upper Pannonian (Upper Miocene) raised beaches covered by travertines (T_{10}-T_{12}); T_0= Paleogene-Neogene planation surface sculptured by Oligocene-Miocene pedimentation with sporadic gravels. Paleomagnetic polarity according to MÁRTON, P. and PEVZNER, M.A.

In the Bakony Mts. (western TM) *basaltic tuffs and lava* were deposited over late Miocene and Pliocene foothill surfaces. The basalt-capped mesas are witnesses of the removal of about 100 to 200 m thick Pannonian sequence.

Neogene and Quaternary geomorphological surfaces (Miocene marine terraces, delta gravel deposits, Pliocene foothill surfaces, Quaternary terraces and alluvial fans) were often preserved by *hard travertine deposits* capping them *(Fig. 4)*. A part of these geomorphological surfaces are predominantly erosional (foothill surfaces, glacis), others were formed by the joint work of accumulation and erosion. The most different elevation of Miocene foothill surfaces, marine terraces and Danube delta gravel renders their correlation difficult. In the Visegrád Gorge of the Danube valley pediments were formed on andesitic rocks, presumably during the same interval.

During the Quaternary some horst groups of the TM were further uplifted in a different manner (max. 200 to 250 m). In this period valley terraces, alluvial fan terraces, cryoplanation glacis surfaces were shaped which are juvenile erosional and accumulational surfaces. The number and elevation of different geomorphological levels are decreasing toward the forelands and basins (PÉCSI, M. *et al.* 1988).

In the Danube bend, near Visegrád, the Mesozoic surface of the TM lies about 1-1.5 km below the sea level, covered by thick Oligocene to middle Miocene epicontinental molasse-like deposits. Volcanic rocks of the Visegrád Mountains and, partly, of the Börzsöny Mountains, cover thick middle Miocene (Badenian) sandy deposits (JUHÁSZ, E. *et al.* 1995). Along the Danube Bend there is a Tertiary molasse corridor, where these volcanic mountains formed during a rather short time, between 15 and 14 Ma BP. This young volcanism along the molasse trough could hinder but not prevent the flow of the Paleo-Danube the carrying water and sediment of confluent rivers from the foreland of the northern Alps, the eastern Alps and western Carpathians towards the Great Hungarian Plain.

Consequently, the Paleo-Danube most probably acted as a morphological and sedimentation agent in the molasse trough between the Buda-Pilis Mts. and Naszály of the TM. Thus, the Miocene quartz-pebble containing delta remnants, high valley foothill surfaces and half plains of planation may be interpreted on the volcanic build-ups around the Visegrád-Gorge.

Erosional surfaces and denudation chronology

In the Transdanubian Mountains the Mesozoic horsts on which bauxite-bearing ancient tropical karst forms are found overlain by thin Upper Cretaceous or Eocene sediments are regarded as *remains of the Cretaceous tropical etchplain* from a geomorphological point of view *(Fig. 3)*. Depending on their orographic position, these buried horsts may occur in uplifted position (summit level), as lower-situated steps or also in threshold position. Their surfaces, however, as fundamental morphogenetic surfaces existed already in the Cretaceous and considerable reshaping did not follow during the subsequent repeated exhumation accompanying uplift. It is also common that the Oligocene sandstone covers conformably the ancient etchplain characterised by tropical tower karst, bauxite and red clay *(Fig. 3)*.

In most cases, during exhumation only the Tertiary sedimentary cover was removed from the horst etchplanated in the Cretaceous and buried in the Tertiary, thus the exhumed ancient etchplain represents the geomorphological surface.

There are horsts in great number covered by Eocene and Oligocene clastic rocks, whose ancient surfaces were not merely lowered but also remodelled. In this case the surface of the horst is identified as a younger reworked e.g. Oligocene geomorphological surface.

It is occasionally difficult to determine the age of remodelling of the uncovered exhumed horst. In these cases one may start from the fact that the surface of horsts of the Transdanubian Mountains was planated already in the Cretaceous, the surface of those of low position slightly changed during the Tertiary, it is inherited. The uncovered horsts of morphologically higher position could be pediplanated in the course of the Paleogene and became pedimented at their rnargin during the Neogene.

Each of the horsts etchplanated in the Cretaceous then buried, semi-exhumed and being uncovered may occur at different elevations *(Fig. 5.)*. Some types can be found eg. at the same height besides each other within the same mountain unit. It is also common that the planated horsts covered by Oligocene sandstone overlie stepwise one another. The surfaces of different heights of these horst types do not represent geomorphological surfaces of different ages.

In the mountain margins the Neogene marine terraces represent usually younger geomorphological surfaces that the uplifted and exhumed horst surfaces. Nevertheless, it is common that the Pannonian marine formations overlie horsts uplifted to 400 to 500 m height which were buried in the Paleogene (Buda Mountains), elsewhere upper Pannonian travertine occurs on the Mesozoic geomorphologic surface (Balaton Upland, ca 300 m above sea level).

In some cases we find foothill surfaces in marginal positions, transformed by Paleogene and/or Neogene pedimentation. These may be further shaped by Quaternary cryoplanation and accumulative glacis formation. This way *generations of surfaces of different ages* may be preserved on horsts or on their vicinities.

On the margins of horsts of the Transdanubian Mountains the Late Cainozoic geomorphological surfaces (marine terraces, pediments, river terraces) were preserved by the hard strata of travertines from the subsequent erosion. Travertines were formed by karst springs in the base level. In the Transdanubian Mountains 12 Neogene and Quaternary geomorphological surfaces were preserved by travertines. This phenomenon is characteristic of the mountain margins and of some larger valleys. In the valley-side terraces a lower sequence of travertines is deposited (between 120 and 250 m altitudes). The higher situated sequence of travertine covers the pediments and marine terraces. To determine their age, fauna remnants paleomagnetic and absolute chronological data were available (PÉCSI, M., SCHEUER, Gy. and SCHWEITZER, F. 1988).

Conclusions

Based on comparative geomorphological observations, a *model of surface evolution through alternating erosion and accumulation* is proposed, which is here used as a tool for understanding the evolution of surfaces on horsts and grabens in the Transdanubian Mountains (TM). This model aims at an improving of accuracy of terminology (PÉCSI, M. 1970a,b, 1975, 1993).

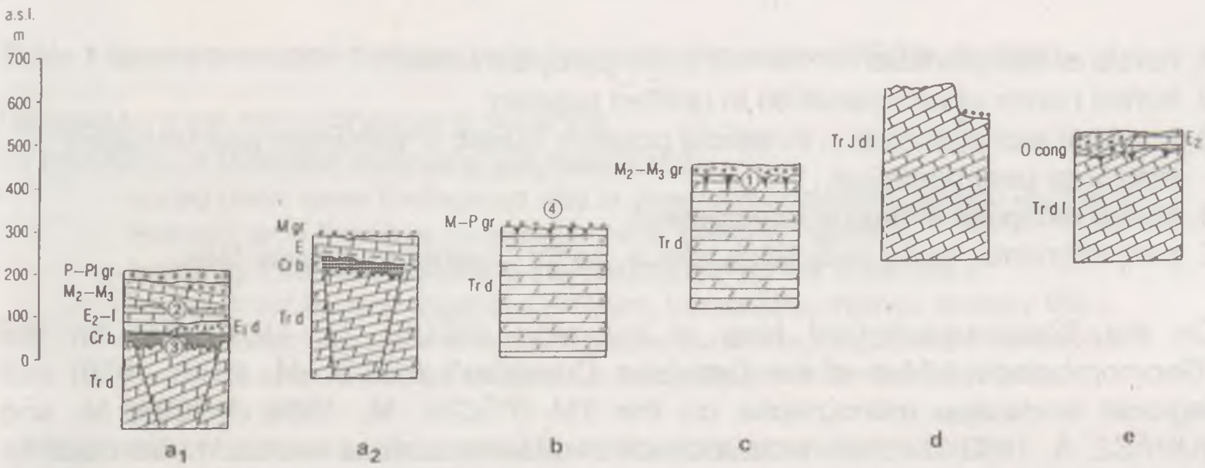

Fig. 5 Geomorphological position of the dislocated and remodelled tropical etchplain remnants of the Transdanubian Mountains (after PÉCSI. M.)
a_1,a_2 = buried surface of etchplain in a sub- or intramontane graben; b = surface of planation in threshold position, exhumed and reshaped etchplain; c = buried planated surface in uplifted position; etchplain remnant partly planated in the course of deposition of Oligocene gravel sheet over it; d = exhumed etchplain in summit position, reshaped etchplain by (peri)pedimentation; e = uplifted, partially exhumed Cretaceous etchplain remodelled by pedimentation during the Tertiary (eg. Oligocene) in the forelands of the crystalline massifs, with conglomerate covers over their subsided part; P-P_1gr = Pliocene-Pleistocene gravel; M_2-M_3 = Middle Miocene marl, limestone and gravel; E_2l = Middle Eocene limestone; E_1d = Lower Eocene dolomite detritus; Crb = Upper Cretaceous bauxite; Tr_3d= Triassic dolomite; Mgr = Miocene gravel; M_2-M_3gr = Middle and Upper Miocene gravel and conglomerate; Tr., J.d.l = Triassic and Jurassic dolomite and limestone; O.cong.= Oligocene sandstone and conglomerate; 1 = remains of tropical weathering, with kaolinite and red clays; 2 = unconformity; 3 = tower karst remnant of a tropical peneplain; 4 = gravel patches on the surface

The basis of this *model for alternating erosion and accumulation* is *that formerly developed* (by tropical etchplanation, pedimentation, pediplanation) *surfaces of erosion are repeatedly reshaped by erosion and accumulation during subsequent geological times. The morphostructural element is repeatedly uplifted and subsided and horizontally displaced by tectonic processes.*

This model proposes that in the TM the conditions resulting in *erosional surfaces*, due to tropical tower-karstic planation and accompanied by bauxite formation, were interrupted by the beginning of the Tertiary. This was mainly caused by changes in climate and in tectonic activities. During the Tertiary the bulk of the TM was repeatedly buried by tectonic subsidence under sedimentary sequences of different thickness. Some regions were partially or entirely elevated and exhumed twice or three times (during the Paleogene, Neogene and Quaternary). The karstic etchplain surface of Cretaceous origin was further eroded or buried under sediments during these repeated burial and exhumation events (e.g. by peripedimentation, formation of marine terraces, or alluvial fans). The TM, subdivided by grabens, contains five different groups of geomorphological surfaces:

1, horsts of etchplanation in summit level, partly exhumed;
2, buried horsts of etchplanation in uplifted position;
3, horsts of etchplanation in threshold position, buried or exhumed and reshaped, mainly by pedimentation;
4, buried etchplain in basins (cryptoplain);
5, peripediments, rocky pediments, glacis, partly covered by alluvial fans.

On the "Geomorphological Map of Hungary" (PÉCSI, M. 1976) and on the "Geomorphological Map of the Danubian Countries" (PÉCSI, M. 1977, 1980) and regional landscape monographs on the TM (PÉCSI, M. 1988, PÉCSI, M. and JUHÁSZ, Á. 1990) the term *erosional-accumulational* surface evolution was used for the development of those geomorphological surfaces for which sufficient information was available, according to the principles and criteria of the proposed model. The model explaining and classifying the erosional surface evolution describes the surfaces of planation, buried surfaces, repeatedly exhumed and eroded planes, illustrates the polycyclic process of their superposition and reveals the main phases of the changes.

After three decades of observations in this field we think that the explanation is not just valid for the individual Intracarpathian Mountains, but may be applied in the cases of the Alpine-Dinarid mountain system, of some European ancient mountains, or of mountains and massifs of various continents.

The superposition of geomorphological levels of different ages could be demonstrated in the case of the units of the TM, using the procedures of denudation- and accumulation chronology *(Table 1)*. The particular case of it has been published several times in Hungarian and in other languages, summarised in a monograph of the Transdanubian Mountains (PÉCSI, M. 1970a,b, 1993; PÉCSI, M. and JUHÁSZ, Á. 1990; PÉCSI, M. *et al.* 1985; SZÉKELY, A. 1972).

In the Gerecse, Buda, and Pilis Mountains (TM) the presence of almost all young geomorphological levels could be demonstrated in some sections, in addition to older ones. In the forelands of these Mountains the higher levels were represented by 3 or 4 Neogene marine terraces and deltas, by 1 to 2 foothill surfaces, and by 4 to 6 Quaternary fluvial terraces *(Fig. 4)*. These geomorphological levels were protected against subsequent denudation by *travertines* capping them. Thus a reconstruction of long-term morphological evolution of geomorphological surfaces became feasible (PÉCSI, M. 1975, 1993; PÉCSI, M. *et al.* 1985).

The chronological classification of the geomorphological surfaces gave us a key to outline the geomorphic evolution of TM during the Cainozoic era.

Table 1 Geomorphological surfaces in the Hungarian mountains (PÉCSI, M 1985)

I REMNANTS OF OLD EROSION SURFACES

1 <u>Remnants of Mesozoic etchplains with tower karst</u>
- buried under lower Cretaceous clay or limestone in plateau position (in the E. Bakony), or in threshold position (in the S. Bakony, Halimba)
- buried by Eocene limestone in summit position (in the Buda Mts.)
- buried under Eocene limestone (at Gánt, Vértes Mts.; Nyírád, Bakony Mts.)
- buried under Oligocene sandstone (in the Buda Mts.) on different elevations
- remnants of an exhumed etchplain in summit position (in the Buda Mts., Keszthely Mts.)

2 <u>Remnants of Paleocene (and mostly Mesozoic) etchplains resculptured by Oligocene and Miocene pedimentation</u>
- etchplain buried by Miocene gravel in summit position (at Farkasgyepü, Bakony Mts.)
- exhumed etchplain with patches of Miocene gravel in summit position (in the Gerecse Mts.)

II REMNANTS OF NEOGENE SURFACES OF PLANATION

1 <u>Miocene raised beaches</u>
- Surface with Karpatian conglomerate (in the northern foreland of Bakony Mts.)
- Surface with Badenian littoral sandy-gravely limestone (in the Visegrád and Börzsöny Mts.)
- Sarmatian raised beach (in the Buda Mts., Balaton Upland)
- Sarmatian pediment (in the Mátra and Zemplén Mts.)

2 <u>Pannonian (Upper Miocene) raised beaches and travertine horizons</u>
- Lower Pannonian (Monacian) raised beach (at Sóskút,. Diósd, in the Buda Mts. and on the Balaton Uplands)
- Delta deposits (Precsákvárian- Csákvárian, the "Billege" and "Kálla" gravel on the Balaton Upland)
- Upper Pannonian (Pontian) raised beach - two surfaces (in the Bakony, Vértes and Buda Mts.).
- Upper Pannonian Csákvárian - Sümegian - Baltavárian) travertine occurring on two or three surfaces (Nos 10-12, at Nagyvázsony, Veszprém Plateau and Várpalota in the Bakony Mts., on Széchenyi- and Szabadság-hill in the Buda Mts., two surfaces in the Gerecse Mts.)
- Upper Pannonian deltaic gravel (on Kőpite hill in the Gerecse Mts.).
- Upper Pannonian-Pliocene basalt lava on pediment (subdivided into two levels?) (e.g. on Kabhegy and Somló hills in South Bakony Mts.).

3 <u>Uppermost Miocene - Pliocene pediments and travertine levels</u>
- Mio-Pliocene pediment (Baltavárian) locally lowers down and forms a double surface of planation (between 360 and 220 m above sea level along the margins of the Transdanubian Mountains).
- Pliocene (Ruscinian-Csarnótian) travertine horizons on pediment (Nos 8 and 9; in the Buda Mts., on the Kőpite-hill at Süttő in the Gerecse Mts)

4 <u>Upper Pliocene (Ruscinian - Csarnótian - Lower Villányian) old alluvial fans and travertine horizons</u>
- the Kemeneshát - Ezüsthegy - Kandikó gravel sheet
- terrace No VIII and travertine No 8 (in the Danube Bend Mts.)
- terrace No VII and travertine No 7 (terrace hills of the Kemeneshát)

III QUATERNARY FLUVIAL TERRACES, ALLUVIAL FAN TERRACES AND TRAVERTINE HORIZONS

- Terrace No VI and travertine No 6 (Upper Villányian)
- Terrace No V (Kislángian - Biharian) and travertine No 5 (Middle Biharian?, of reversed polarity)
- Terrace No IV (Middle Biharian, Vértesszőlős phase), > 350 Ka, terrace and travertine are of normal polarity
- Terrace No IIIa and travertine No 3a (270 Ka) (in the Gerecse Mts.)
- Terrace No IIb (R_3-W_1) with travertine cover (120 to 70 Ka old)
- Terrace No IIa (W_3), ca 26 to 12 Ka
- flood-plain No I and Holocene travertine No 1, from 11 Ka to present

Notes

[1]The genetic and topographic interpretation of the concept of relief planation is rather diverse in the literature. Taking into consideration all definitions, both narrow and broad, it emerges that *surfaces of planation are considered (plane) surfaces of considerable extent and low relief energy, over a stable or gently rising base. They are sculptured by processes of destruction, and by a well-defined equilibrium of uplift and degradation.*
While some authors consider surfaces of planation to be results of sculpturing by a single erosive agent, others think that they are polygenetic; i.e. they result from the interaction of several processes the rates of which vary in time and space. Some authors believe that surfaces of planation are polygenetic also in space. Their complex of forms includes not only surfaces of erosion, but also surfaces of accumulation.
[2]*Davis* assumed periods of long tectonic rest in the evolution of a mountain; the evolution during such a period produces a *peneplain* in the penultimate stage of the *cycle of erosion*, which subsequently undergoes repeated uplifting. On the mountain margins, at the base level of erosion, *partial peneplains* come into existence. Wherever and whenever the periods of tectonic stillstands were not sufficiently long for the process of peneplanation to completely wear away the relief formed during the previous cycle and subsequently uplifted, there, according to DAVIS, *occur remnants of older peneplains* at higher altitudes, *in a stepwise arrangement.*
[3]In the Penckian interpretation of stepped *Rumpfflächen* (piedmont benchlands) the initial surface is the *"Primärrumpf"*, but it may also be the Davisian peneplain, the *"Endrumpf"*, *"Endpeneplane"*. As a result of arching, a process extending in area and accelerating in time, the longitudinal profiles of rivers are broken and the valley flanks gradually retreat and broaden at the expense of the higher surface. The broadening arch embraces an increasingly wide area and thus and increasingly number of younger step surfaces are connected to the most highly elevated central arch. It is this system of stepwise repeated surfaces of planation that was called *"Piedmonttreppen"* by an ever broadening area, rather than to a protracted and constant-rate uplift.
[4]*Pediplains have usually been deduced from pediments* (MAXSON, J.M: & G.H. ANDERSON 1935, HOWARD, A.D. 1942, MACKIN, J. H. 1970). It was in connection with these forms that American geologists and geomorphologists first came to attribute a decisive role to climatic factors. They interpreted as pediplains a number of extensively planated surfaces regarded as peneplains by *Davis*.
KING, L.C. (1962) has lately expressed the view that pediplanation is the most general form of surface lowering, substituting, as it were, the periplanation concept for the Davisian peneplain concept. In this way, however, KING (1949, 1962) gave an unduly broad context to the term pediplain, under which heading he included all the extensive planated surfaces of all continents as far back as the Cretaceous. In King's opinion pediplains are typical of semiarid tropical zones, but may also develop at lower intensities under moderately humid conditions. He considers the differences between forms developed in arid, semiarid and moderately humid climatic zones to control merely the intensity of development.

Another open question concerns the criteria of identification for the pediplain, as a remnant of some planated surface outside the semiarid zone.

[5]*Tropical surfaces of planation, the concept of etchplanation*

WAYLAND E.J. (1933) introduced the *concept of etchplain*, the etchplanation has been attributed to tropical deep weathering followed by removal (stripping) of the thick regolith zone. The idea has been elaborated and further developed by BÜDEL, J. (1957), partly modified by BULLA B. (1958), LOUIS, H. (1957) and some others.

The concept, that extensive surfaces of erosion are most readily formed under humid or alternately humid and arid tropical climates, has become more and more widely accepted. The initiators of the theory explained the lowering and smoothing of large surfaces by extensive colloidal and subcolloidal weathering as well as by large scale slopewashing. Büdel interpreted the evolution of the tropical surfaces of planation by developing the theory of "duplicate planation surfaces" (doppelte Einebnungsflächen).

In the zone of tropical slopewash, the surfaces are thickly covered with products of weathering, underlain by a less thoroughly smoothed but still hummocky relief of unweathered rock (e.g. granite). This deeper interface is the basal front of planation, smoothed by weathering. Double planation takes place, on one hand, by slopewash on the surface cloak of weathering products (Spüloberfläche) and, on the other hand, by subsurface weathering on the deeper interface.

[6]Sporadically in the Carpathian Basin red clays occurring in subaeral Neogene deposits, in basin position, are interfingered by series of variegated clays, sandy clays, silts and sands. These sequences, under optimal geological and climatic conditions, could cover most of the Pliocene and the start of their formation can be dated to the late Miocene (ca 2-5.6 Ma, PÉCSI, M. 1985; PÉCSI, M. *et al.* 1988). The red clay together with the intercalated sequence are also products of cyclic climatic changes. They represent subtropical subhumid climate with alteration of warm-rainy and warm-dry seasons, succeeded by warm semiarid climatic intervals preventing red clay formation but favouring pediment development.

References

BALLA, Z. 1988. Tertiary paleomagnetic data for the Carpatho-Pannonian region in the light of the Miocene rotation kinematics. - *Földtani Közlöny*. 139. pp. 67-98.

BÁLDI, T. and KÓKAY J. 1970. Die Tuffitfauna von Kismaros und das after des Börzsönyer Andesitvulkanismus. - *Földtani Közlöny*. 100. pp. 274-284.

BÁLDI, T. 1982. A Kárpát-Pannon rendszer tektonikai és ősföldrajzi fejlődése a középső tercierben. (49-19 millió év között) (Tectonic and paleogeographic evolution of the Carpatho-Pannonian system in the middle Tertiary, between 49-19 Ma BP.). - *Őslénytani Viták*. 28. pp. 79-155.

BÁRDOSSY, Gy. 1973. Bauxitképződés és lemeztektonika (Bauxite formation and the plate tectonics). - *Geonómia és bányászat. MTA X. osztály közlemények*. 6/1-4. pp. 227-240.

BÁRDOSSY, Gy. 1977. Karsztbauxitok (Karstic bauxites). - Akadémiai Kiadó. Budapest, 413. p.

BREMER, H. 1986. Geomorphologie in den Tropen-Beobachtungen, Prozesse, Modelle. - *Geoökodynamik*. 7. pp. 89-112.

BULLA, B. 1958. Bemerkungen zur Frage der Entstehung von Rumpfflächen. - *Földrajzi Értesítő*. 7. 3. pp. 266-274.

BÜDEL, J. 1957. Die "doppelten Einebnungsflächen" in feuchten Tropen. - *Zeitschrift für Geomorphologie*. N.F. 1. pp. 201-228.

DAVIS, W.M. 1906. Geographical Essays. - Ginn, Boston. New edition: 1954, Dover, New York, 777 p.

DAVIS, W.M. 1922. Peneplains and the geographical cycle. - *Bull. of Geol. Soc. of Amerika.* Baltimore. Vol. 33. pp. 587-598.
FÜLÖP, J. 1989. Bevezetés, Magyarország geológiájába (Introduction in Geology of Hungary). Akadémiai Kiadó, Budapest. 246 p.
GÉCZY, B. 1974. Lemeztektonika és a paleontológia (Plate tectonics and paleontology). - *Földtani kutatás.*17/3. pp. 17-20.
HÁMOR, G. 1989. Paleogeographic reconstruction of Neogene plate movements in the Paratethyan realm. - *Acta Geologica Hungarica.* 27/12. pp. 5-21.
HORVÁTH, F. 1974. Application of plate tectonics to the Carpatho-Pannonian Region. - *Acta Geologica Hungarica.* 18. pp. 243-255.
HORVÁTH, F., STEGENA L. and GÉCZY, B. 1974. Szialikus és szimaikus ívközi medencék (Sialic and simaic inter-arc basins).- *Földtani Kutatás.* 17/3. pp. 11-16.
HOWARD, A.D. 1992. Pediment passes and the piedmont probleme. - *Journal of Geomorphology.* 5. pp. 1-31.
JASKÓ S. 1988. A Magyar-középhegység neogén rögszerkezete (The Neogene block structure of the Central Hungarian Range). - *Földtani Közlöny.* 118. pp. 325-332.
JÁMBOR Á. 1989. Review of the geology of the s.l. Pannonian formations of Hungary. - *Acta Geologica Hungarica.* 32. pp. 269-324.
JUHÁSZ Á. 1988. A Bakonyvidék (The Bakony Region). - In: Pécsi, M. (ed.) A Dunántúli-középhegység B. (Magyarország tájföldrajza 6). Akadémiai Kiadó, Budapest. pp. 31-101.
JUHÁSZ, E., KORPÁS, L. and BALOGH, A. 1995. Two hundred million years of karst history, Dachstein Limestone, Hungary. - *Sedimentology.* 42. pp. 473-489.
KÁZMÉR, M. 1984. A Bakony horizontális elmozdulása a paleocénben (Horizontal displacement of the Bakony Mountains during the Paleocene). - *Általános Földtani Szemle.* 20. pp. 53-101.
KING, L.C. 1949. The pediment landforms: some current problems. - *Geological Magazine* 86. pp. 245-250.
KING, L.C. 1962. The Morphologische Analyse. - Oliver & Boyd, Edinburgh and London. 699 p.
KRETZOI M.and PÉCSI M. 1982. A Pannóniai-medence pliocén és pleisztocén időszakának tagolása . - *Földrajzi Közlemények.* 30. (106) 4. pp. 300-326.
KRETZOI, M. and PÉCSI, M. 1979. Pliocene and Pleistocene development and chronology of the Pannonian Basin. *Acta Geologica Acad. Sci. Hung.* 22. 1-4. pp. 3-33.
LUIS, A. 1957. Rumpfflächenproblem, Erosionszyklus und Klimamorphologie. - Geomorphologische Studien, Mahatschek Festschrift. Berlin. pp. 19-26.
MACKIN, J.H. 1970. Origin of Pediment in the Western United States. - In: Pécsi, M. (ed.) Problems of relief planation. (Studies in Geography in Hungary 8.) Akadémiai Kiadó, Budapest. pp. 85-105.
MAXON, J.M. and ANDERSON, G.H. 1935. Terminology of surface forms of the erosion cycle. - *Journal of Ecology.* 43. pp. 88-96.
MÁRTON, P. and SZALAY, E. 1981. Mezozoic paleomagnetism of the Transdanubian Central Mountains and its tectonic implications. - *Tectonophysics* 72. pp. 129-140.
MINDSZENTY, A., KNAUER, J. and SZANTNER F. 1984. Az iharkúti bauxit üledékföldtani jellegei és felhalmozódási körülményei (Sedimentological features and the conditions of accumulation of the Iharkút bauxite deposit). - *Földtani Közlöny.* 114. pp. 19-48. (English summary: pp. 41-44.)
McGEE, W.J. 1897. Sheetflood erosion. *Bull. of Geological Society of America.* 8. pp. 87-112.

PENCK, W. 1924. Die Morphologische Analyse. - Stuttgart. 277 p.
PÉCSI M. 1963. Hegylábi (pediment) felszínek magyarországi középhegységekben. - (Summary in German: Fußflächen in der Ungarischen Mittelgebirge). - *Földrajzi Közlemények*. 11. (87) 3. pp. 195-212.
PÉCSI, M. 1968. Denudational levels of the Hungarian Middle Mountains with special regard to pediment formation. - The geomorphological and terminology problems of the denudation features of middle mountains and their pediments (Symposium). Inst. of Geogr. Hung. Acad. of Sci., Budapest. pp. 24-36.
PÉCSI M. 1969a. A Balaton tágabb környékének geomorfológiai térképe (Geomorphological map of the broader environs of Lake Balaton). Kísérlet Magyarország áttekintő (1:300 000-es) geomorfológiai falitérképének elkészítéséhez. - *Földrajzi Közlemények*. 17. (93) 2. pp. 101-112.
PÉCSI M. 1969b. A hegységek és előterük lepusztulásformáinak kutatásáról rendezett nemzetközi szimpózium főbb eredményei (The geomorphological and terminology problems of the denudation features of middle mountains and their pediments). - *MTA Föld- és Bányászati Tud. Oszt. Közleményei*. 2. pp. 319-321.
PÉCSI, M. 1970a. Geomorphological regions of Hungary. (Studies in Geography in Hungary 6). Akadémiai Kiadó, Budapest. 45 p.
PÉCSI, M. 1970b. Surfaces of planation in the Hungarian mountains and their relevance to pedimentation. - In: Pécsi, M. (ed.) Problems of relief planation. (Studies in Geography in Hungary 8.) Akadémiai Kiadó, Budapest. pp. 29-40.
PÉCSI M. 1974. A Budai-hegység geomorfológiai kialakulása, tekintettel hegytípusaira (Geomorphic evolution of the Buda Mountains and its mountain types). - *Földrajzi Értesítő*. 23. 2. pp. 181-192.
PÉCSI M. 1975. Geomorphological evolution of the Buda Highland (Hungary). - *Studia Geomorphologica Carpatho-Balcanica*, Kraków. 9. pp. 37-52.
PÉCSI M. 1976. Magyarország geomorfológiai térképe (The geomorphological map of Hungary. 1:500 000. Legend). - *Földrajzi Közlemények*. 24. (100) 1-2. pp. 34-41. (in Hungarian). pp. 42-44. (in English).
PÉCSI, M. 1977. Geomorphological map of the Carpathian and Balkan regions (1:1 000 000) + Part of the 1:1 000 000 scale geomorphological map of the Carpathian region (Map). - *Studia Geomorphologica Carpatho-Balcanica*. 11. Kraków. pp. 3-31.
PÉCSI, M. 1980. Erläuterung zur geomorphologischen Karte des "Atlasses der Donauländer". - Österreichische Osthefte. 22. 2. pp. 141-167.
PÉCSI, M. 1983. A Dunántúli-középhegység sasbérc felszínei és a denudációs kronológia (Horsts in the Transdanubian Mountains and denudation chronology). - *Földrajzi Értesítő* 32. 3-4. pp. 504-505.
PÉCSI, M. 1987a. Domborzat (Relief). - In: Pécsi, M. (ed.) A Dunántúli-középhegység, A. (Magyarország tájföldrajza 5.) Akadémiai Kiadó, Budapest. pp. 140-176.
PÉCSI, M. 1987b. Domborzatfejlődés és a geomorfológiai szintek korrelációja (Relief evolution and correlation of geomorphological levels). In: A Dunántúli-középhegység A. (Magyarország tájföldrajza 5.) - Akadémiai Kiadó, Budapest, pp. 131-139.
PÉCSI, M. 1988. Geomorfológiai szintek kora a Magyar-középhegységben. (Summary in English: Age of geomorphological surfaces in the Hungarian Mountains.) - *Földrajzi Közlemények*. 36. (112) 1-2. pp. 28-41.

PÉCSI, M. 1993. Landform evolution model of alternating erosional-accumulational geomorphic surfaces. - *Indian Journal of Landscape Systems and Ecological Studies.* 16. 2. 1-7.
PÉCSI, M. and JUHÁSZ, Á. (eds) 1990. Excursion Guide. Symposium and Field Excursion in Bakony Mountains. First Hungarian-Slovene Geographical Seminar. 27-28. Sept. 1990. Geogr. Res. Inst. Hung. Acad. Sci., Budapest. 65 p.
PÉCSI, M., SCHEUER, GY., SCHWEITZER, F., HAHN, GY. and PEVZNER, M.A. 1985. Neogene-Quaternary geomorphological surfaces in the Hungarian Mountains. - In: Kretzoi, M. and Pécsi, M. (eds) Problems of the Neogene and Quaternary. (Studies in geography in Hungary 19.) Akadémiai Kiadó, Budapest. pp. 51-63.
PÉCSI, M., SCHEUER, GY. and SCHWEITZER, F. 1988. Neogene and Quaternary geomorphological surfaces and lithostratigraphical units in the Transdanubian Mountains. - In: Pécsi, M. and Starkel, L. (eds) Paleogeography of Carpathian Regions. Geogr. Res. Inst. Hung. Acad. Sci., Budapest. pp. 11-41.
PÉCSI, M.-SZILÁRD, J. 1970. Planated surfaces: Principal problems of research and terminology. - In: Pécsi, M. (ed.) Problems of relief planation (Studies in geography in Hungary 8.) Akadémiai Kiadó, Budapest. pp. 13-27.
SÁG, L. and PÉCSI, M. 1987. Kainozoikum (Cenozoic). In: A Dunántúli-középhegység A. (Magyarország tájföldrajza 5.). Akadémiai Kiadó, Budapest, pp. 75-122.
SCHWEITZER, F. and SCHEUER, GY. 1988. A Gerecse és a Budai-hegység, édesvízi mészkőösszletei (Travertines in the Gerecse and Buda Hills). - *Földrajzi Tanulmányok.* 20. Akadémiai Kiadó, Budapest. 129 p.
STEGENA, L. and HORVÁTH, F. 1978. Kritikus tethysi és pannon tektonika. - Budapest, *Földtani Közlöny.* 108. pp. 149-157.
SZÉKELY, A. 1972. Az elegyengetett felszínek típusainak rendszere magyarországi példákon. (Summary in German and in English: A system of planation surface type - on examples from Hungary). - *Földrajzi Közlemények* 20. 1. pp. 43-59.
WAYLAND, E.J. 1937. Peneplains and some erosional platforms. - *Bulletin geological Surawy Uganda.* Ann. rest. Bull. 1. pp. 77-79.
WEIN, GY. 1977. Magyarország neogén előtti szerkezetföldtani fejlődésének összefoglalása (A review of pre-Neogene tectonics in Hungary) - *Földrajzi Közlemények.* 25. pp. 302-328.
WEIN, GY. 1978. A Kárpát-medence kialakulásának vázlata (An outline of the evolution of the Carpathian Basin). - *Ált. Földtani Szemle.* 11. pp. 5-34.

Geomorphology And Global Habitability

BAKER, Victor R.
Department of Geosciences, University of Arizona
Tucson, AZ 85721 USA

Much current global change and natural hazard research is of limited value because of an overemphasis on prediction through idealized conceptual models predicated upon unverifed assumptions. To understand environmental change one needs scientific experience of such change as a complement to the conceptualization of that change. Geomorphology, a major science of natural experience, has largely been marginalized by the value systems imposed by the earth-system science emphasis of modern global change research.
Current intemational science initiatives to understand global change focus on predictionachieved through mathematical models. It is assumed that this approach will provide the essential basis for policy- and decision-making to mitigate threats to global habitability. Because such models are strictly unverifiable in the real world. accurate foreknowledge of the future is ari impossible goal. As a practical matter, decisions will be made on the basis of perception, grounded in the available experience of change. The greatest repository of Earth experience capable of stimulating human perception is the Earth's surface and evidence of its geomorphological change. In studying this record, geomorphologists employ synthetic reasoning, using retroductive (causal) inference, to interpret indices (signs) of processes that reveal the natural patterns (habits) of Earth experience through time and space. Discovery of anomalous phenomena leads to the need for revising prior conceptualizations (models), refomulating them to be more in accord with reality. An example is the recent discovery in tropical river paleoflood records that large floods may be preferentially clustered in recent decades. If corroborated by further study, this may indicate an influence of global greenhouse warming on monsoonal circulation and tropical storms. Such change could have profound implications for global habitability.

Introduction

Human civilization has long been at risk from environmental change. Droughts, floods, and soil degradation have all imperiled the infrastructure of past societies. Ancient civilizations of once-fertile river valleys have been destroyed by the direct and indirect consequences of these environmental changes (THOMAS, W.L. 1956). Against a background of continuing massive transformation of the Earth by human action (TURNER, B.L. II *et al.* 1990), in recent years scientific concern with "global change" has increasingly focused on issues such as greenhouse watming, ozone depletion, desertification, and deforestation. International programs for "earth-system science" and "geosphere-biosphere" study are being actively promoted for achieving solutions to these problems. In the dozen years since their inception (PERRY, J.S. 1991) these programs have now moved to the forefront of concern by the international science community. For the United States research strategies have been established to achieve an understanding of global change (Committee on Global Change 1990). The primary strategy of "integrated modeling of the earth system" is being implemented into policy for the funding of U.S. science. The goal of the 1994 U.S. Global Change Research Program (Committee on Earth Sciences 1993) is "to produce predictive understanding of the earth system to support national and international policy-making activities across a broad spectrum of global, national, and regional environmental issues."

A great weakness of various initiatives in scientific global change research and in the assessment of natural hazards, such as floods, is their overemphasis on prediction through idealized conceptual models predicated upon unverified assumptions. The problems of human habitability on planet Earth center on the reality of immense populations of Asians, Africans and South Americans, who live on lands sensitive to continental environmental change. Coping with this change requires not merely ideal model predictions of future climate; it requires a profound experience-based scientific understanding of such change. Broad-scale experiential science of real, continental land-water change is the natural work of geomorphologists and surficial geologists. Their efforts may serve some role in providing information on landscape process changes as a source of testing models for predicting such changes. However, by far the more imponant goal of their work is to discover unforeseen workings of the natural and human-modified that will require new or revised models (hypotheses) for their explanation. I am concerned that this latter goal is being impeded by the present overemphasis on predicting the "earth system" and "reducing the uncertainties" in that predictive enterprise. Reasons for this concern, and our possible response as geomorphologists will be explored in this essay.

The Earth-system Science Approach

Human beings live on the land surface of the Earth. Their existence is interwoven with and dependent upon that surface which they inhabit. It was for this reason that the original designation of the global science initiatives of recent years began with the name "global habitability" (GOODY, R. 1982). The original name, now superseded by "global change" and "earth-system science", reminds us of the real reason that such science is needed for the future. Humankind desires a habitable planet for its long-term existence. This application is the desired outcome of the science that society is asked to support with substantial resources that might otherwise be spent on many worthwhile nonscientific projects. It is well to remember that while "...science expects autonomy and support ... society expects substantial benefits..." (BYERLY, R. and PIELKE, R.A. 1995). The U.S. Global Change Research Program was initiated in 1989 to provide a strategy to enhance the relevant research activities of various federal agencies. The program's initial goal was stated, "...to provide a sound scientific basis for national and international decision making on global change issues" (Committee on Earth Sciences 1989). By 1994 this goal had been restated, "... to produce a predictive understanding of the earth system to support national and intentional policymaking activities across a broad spectrum of global, national, and regional environmental issues" (MOLNIA, B.F. 1994). MAHLMAN, J.D. (1989, p.71) provided the following succinct description of the program:

Through careful, long-term research on observation, modeling, and analysis, our scientific uncertainties will decrease and our confidence for predicting details of the climate system and its changes will gradually improve... the societal need for accurate and detailed climate predictions will increase... (and the) effort to meet these societal challenges will require... the world scientific community in a sustained effort spanning decades.

In 1986 the Intentional Council of Scientific Unions (ICSU) established the International Geosphere-Biosphere Programme (IGBP). This international effort has taken up the same themes of earth-system science, predictive modeling, and reducing uncertainties (IGBP,1992). For example, various climate-model simulations of the idealized "earth system" are developed to show near-future changes in atmospheric parameters caused by human-induced increases in radiatively active gases (HOUGHTON, J.T. et al. 1990). Some of these climate modeling simulations have already indicated the theoretical possibility for alarming impacts of an increasing greenhouse effect on regional climatological and hydrological factors, including droughts and flood-causing storms (HANSEN, J. *et al.* 1989). However, the various modeling scenarios are also subject to considerable debate concerning the inherent uncertainties which may limit their use as a basis for what could be extremely expensive societal response (SCHLESINGER, M.E. and JIANG, X. 1991). The debate poses the following dilemma: Should society take drastic action to avert a predicted calamity or should it wait until uncertainties in the prediction are reduced to a comfortable level, at which time the calamitous consequences may be irrevocable?

Clearly, the drastic action needed to avert environmental calamity is not forthcoming. To reduce the uncertainties that preclude action there must be hard facts. One means advocated to obtain these facts is that massive programs of satellite, aircraft, and ground observations must be used to document the changing global earth system (Earth System Science Committee, 1988). Aside from the costs of such programs, at a time when "big science" must compete with many deserving social programs for government financing, there lingers doubt that intensive modern observations will indeed provide the needed basis for action. By the time the relevant changes are eventually documented, and modeled simulations verified against measurements, the projected calamitous global changes may be irrevocable.

There is another approach to resolving this paradox of threatening environmental change and coincident paralyzing inaction to cope with that change. There exists right now a great repository of experience on the global changes of our planet. That repository constitutes the open system of reality that must be understood in order to interpret properly the isolated systems described by the models. Moreover, we now possess the tools with which to open up that repository. Just as the computer revolution has enhanced the scientific ability to deduce future consequences of antecedent conditions, a less heralded revolution has occurred in our ability to infer the antecedents of those consequences that are preserved in the landforms, sediments, and active processes on the surface of the planet. But we are not making best use of this revolution. Consider the immense opportunity afforded through remote sensing from space (SHORT, N.M. and BLAIR, R.W. 1986). In the "predictive understanding" approach of earth-system science the features shown on these images are carefully measured in terms of readily quantifiable parameters. The measurements are then used to parameterize or to test the validity of predictive models. The goal of such science is to formulate the best possible predictive model, which policymakers and the general public believe will tell them how to manage the great and pressing problems for the future habitability of our planet. This goal underlies much of the international scientific effort to provide a scientific basis for understanding the earth system and for responding to global environmental change.

There is a profound flaw in the "predictive understanding" approach to global change science. Working scientists know that predictive models can never provide satisfactory bases for action because their purpose is to help advance understanding, not to tell us what to do. Science has never advanced by proving that some model works; it has always advanced by showing that a model does not work and by replacing the falsified model with one that better explains the current perspective on the facts. The predictions of models make this replacement process more efficient by demonstrating inadequacies of present theory when compared to the facts. When the scientist turns up surprising facts that do not fit the model, facts that stimulate the formulation of new models, then one has what science really seeks: discovery. Thus, I argue that the most important emphasis for geomorphological remote sensing from space is not to improve models, making them more elegantly predictive, but to make discoveries that lead us more efficiently to discard the existing models, to stimulate the search for better ones, and thereby to enhance our understanding of nature. Geomorphologists do not observe and measure solely to test some prevailing model or hypothesis. Rather, geomorphology begins with observations for the purpose of inventing hypotheses that explain the imaged landscape in a manner consistent with experience and known physical law. The interpretations are tentative, subject to verification on the ground. However, they do not arise film ideal theorizing; the factual content of the image itself provides the basis for hypothesizing.

This reasoning process has some interesting advantages over the theory-dominated approach. When one's concern is not with objectively measuring parameters for theory construction, attention can be drawn to oddities. For this discovery process to bear fruit, however, it must be valued, and geomorphology has been undervalued in the study of global environmental change. Why is this?

Reductive Axiology of Earth-system Science

Axiology is the philosophical theory of values. Axiology is usually considered in regard to ethics and aesthetics for arts, such as politics, music, and literature. Science, in contrast, is often claimed to be value-free. The claim is possible only through ignorance of scientific practice.

Working scientists, in their own judgments and in the peer-review or funding decisions relating to work by their colleagues, apply value decisions in abundance. WEINBERG, A.M. (1970) even gives a useful list of such values: (1) pure is better than applied, (2) general is better than particular, (3) search is better than codification, and (4) paradigm breaking is better than spectroscopy.

Value (1) presumably derives from the disciplinary structure of science in which problems arise from the immanent logic of those disciplines, rather than from needs outside that discipline or even outside science itself (WEINBERG, A.M. 1970). Value (2) holds the general to be better than the particular (WIGNER, E. 1964). These values also derive from a reductive version of parsimony with the goal of explaining as much as possible with as little as possible. In pure science one seeks to reduce a set of related events to a single general principle. Value (3) holds that the search for new knowledge is superior to codification of existing knowledge. Value (4) holds that revolutionary science in the sense of KUHN, T.S. (1962) has greater value than the adding of details within some scientific paradigm, which WEINBERG, A.M. (1970) labels "spectroscopy." This last value holds an interesting relationship to the others. It suggests that the discovery of anomalies in the existing paradigms is valued when these overthrow existing generalizations. The anomalies are particulars that don't fit. In this case the particulars are valued, violating value (2). Thus, the axiology (value system) of science has a built-in logical inconsistency, one that is important to understanding the relationship of earth-system science to geomorphology.

The earth-system science of global environmental change seeks a predictive understanding of the future. In seeking this path it makes a value choice, favoring a mathematical/predictive approach (value 2) over a naturalistic/historical one. Any such value choice will result in a kind of hierarchy in the sciences. For this value choice, predictive and experimental sciences that are pure (value 1) occupy top positions in the hierarchy while the mathematically less sophisticated historical and descriptive sciences, especially when applied, fill in the low positions (eg., ALVAREZ, W. 1991). Of course, such classifications are arbitrary and nontestable; they are philosophical, not scientific. Nevertheless, they are assumed by many scientists, so this axiology becomes very important in the practice of science. The assumption of philosophical ascendancy for the mathematical/predictive approach results in a rather specific manner by which geomorphology becomes incorporated into predictive earth-system science of global environmental change. For this reason the comparison of scientific approaches requires careful attention.

Mathematical/predictive sciences are best exemplified in the experimental/theoretical methodology of classical physics. Indeed much of philosophy of science is written as though the words "physics" and "science" are interchangeable. Physics is "the science devoted to discovering, developing and refining those aspects of reality that are amenable to mathematical analysis" (ZIMAN, J. 1978). Its approach is conceptual, seeking universal classes of phenomena that can be generalized by means of the underlying physical laws presumed to govern nature (value 1). Its abstract laws, theories, and relationships must be objectively verified or tested against measured reality through controlled experimentation. As Sir Francis Bacon noted, scientific experiments are questions put to nature. However, the need for objective control means that questioning occurs as an interrogation (KELLER, E.F. 1985) in which the facts of nature are expressed through numerical measures comparable to those generated by the theoretical representation of its essential underlying laws. In this context geomorphology furnishes factual data that exemplify environmental change. Comparison of these realized results (completed "natural experiments") to the theoretical predictions results in scientific validation of theories that are expressed through predictive models.

In the modeling of climate change one uses the analytical reasoning process of mathematical physics. This means that first principles are assumed and that consequences are deduced according to structured logic, often mathematical, from those principles. This deduction is what physicists mean by a "prediction." It is a popular misconception held even by some scientists that a scientific prediction is a prophesy of future events. Prophesies are the province of mystics, not scientists. Scientific predictions are logical deductions, completely developed in the ideal world of scientific theory. For physics. the one contact with reality comes in the match of this deduced consequence ("prediction") with a measured property of nature. The match is confirmed by the method of an experiment, which is a defined element of the real world controlled so as to check the investigator's theories about that limited aspect of reality.

Prediction as preknowledge of future events requires a faith in immutable, invariant lawlike behavior in nature. The more flexible concept of logical consequences allows an expectation of the future behavior subject to confirmation by test (experiment). Thus, a balance is achieved in theoretical/experimental sciences like physics whereby theorizing (modeling) is balanced by experiments. However, another assumption in this logic is that the mathematical theorizing cannot be balanced by tests for the whole, connected world of reality. Rather, this balance occurs in reduced, simplified elements, sometimes termed "systems." Proper validation, verification, or confirmation are only possible in artificial closed systems, not in the open systems that more closely resemble the real world (ORESKES, N. *et al.* 1994).

The logic of some global-change science seems to embody the dual fallacies of (1) prediction as prophesy, and (2) verification of models leading to (1) when the uncertainties are sufficiently reduced. The assumed lawlike construction of models allows them to project both forwards and backwards in time. Extrapolations to past states (retrodictions) can specify past effects, such as climatic or hydrological parameters, that are consequent to the physical laws employed in the model. It is assumed that the comparison of these predicted effects to the reconstructed past can verify or calibrate the model. Presumably, the appropriately verified or calibrated the model will better prophesize the future. However, confirmation of such models for the complexity of the natural world is precluded both on logical grounds and because of incomplete access to the relevant natural phenomena (ORESKES, N. *et al.* 1994).

Retroductive Axiology of Geomorphology

The naturalistic/historical sciences do not focus on idealized theories verified in experimental laboratories. Rather, their prime concern is with realized phenomena observed in the natural world, uncontrolled by artificial constraints. By not limiting herself to the world amenable to mathematical analysis, the naturalistic scientist takes the world as it is. Rather than general principles of universal application, it is concrete particulars that are the focus of attention. A particularly rich source of such reality is the various evidence of happenings in the past. Hence, the naturalistic sciences merge with the historical. Data do not serve the interrogative function of experiments designed to verify. Instead, the observations of phenomena are revealed as signs, providing a language for what CLOOS, H. (1953) termed a "conversation with the Earth." The observations do not serve primarily in the menial function of model validation. Rather, they provide inspiration for hypotheses, as classically described by GILBERT, G.K. (1886, 1896). Hypothetical reasoning, therefore, provides a kind of logic, or inference, through which one can distinguish the naturalistic/historical sciences (e.g., CHAMBERLIN, T.C. (1890) from the mathematical/predictive.

In the hypothetical reasoning of naturalistic/historical sciences like geomorphology, inference is made of cause from effect, or "consequent" from "antecedent" as

GILBERT, G.K. (1886) described it. This mode of inference is synthetic, not analytic/reductive. Unfortunately, this inference is commonly confused with induction. Rather than inferring cause from effect, or "antecedent" from "consequent" to generate a hypothesis, induction infers a rule or law from the instances of that rule or law in operation, as a test of some hypothesis. As noted by VON ENGELHARDT, W. and ZIMMERMANN, J. (1988), synthetic reasoning to some hypothesis was described in considerable detail in the late l9th century by the American logician Charles PEIRCE. PEIRCE variously named this reasoning "retroduction" or "abduction." He traced the latter term to use by Aristotle and specifically associated it with geology (BAKER, V.R. in press). While retroduction/ abduction is clearly important in geological geomorphology (BAKER, V.R. and TWIDALE, C.R. 1991; RHOADS, B.L. and THORN, C.E. 1993), nevertheless, it might appear to be an issue of obscure logic. Indeed, there is considerable controversy on this point by philosophers of science, many of whom believe "a logic of discovery" to be impossible (LAUDAN, L. 1980).

The axiology of reductive analytical science values the simplicity or parsimony of its theories, the elegance of its mathematics. It is well to remember that these are qualities of our conceptions or idealizations. The axiology of retroductive/synthetic science places values on the naturalness of hypotheses. Rather than emphasizing the logical quality of an answer imposed by theory upon nature, through retroduction geomorphology discovers phenomena that raise a new issue: Is the correct question being asked? Retroduction points in the direction of formulating a new model, or revising the old one, such that the newly discovered reality is incorporated into the reformulation.

Retroduction, or abduction, is a characteristic reasoning mode of the Earth sciences (VON ENGELHARDT, W. and ZIMMERMANN, J. 1988). Its employment involves synthetic reasoning, often using analogies, applying the classical doctrines of commonsensism, fallibilism, and realism (BAKER, V.R. 1994a). Synthetic thinking is the continuous activity of comparing, connecting, and putting together thoughts and perceptions. The focus is on deriving hypotheses from nature rather than on applying elegant theories. Analysis may well follow retroduction, but not to provide ultimate answers for intellectual puzzles predefined by limiting assumptions imposed upon the real world. Rather, this analysis allows the investigator to consider the consequential effects of hypotheses. It is important that the latter be suggested by our experience with nature, through what GILBERT, G.K. (1886, 1896) termed "analogy," rather than by our theories of nature.

To achieve understanding of the global Earth environment, geomorphologists study various indices (signs) of Earth processes in a manner consistent with the best available physical theory. This is done not merely to develop a unique story of process operation, but also to characterize the complex Earth processes that cycle over scales of time and space, and defy conventional measurement. Without this understanding, at a minimum theoretical modeling is untested. More important, however, is the recognition of anomalous behavior in the real, model-prototype conditions that would not have been anticipated in its hypothesized theoretical representation. Such anomalies provide the driving inspiration for scientific discovery. In this manner retroductive geomorphology reveals the natural patterns (habits) of the environment as they occur in time and space.

Policy Issues

The prospects of global environmental change adverse to human habitability of the planet pose an immense challenge to science. Not only must good science be done, but that science must effectively translate into public policy. The latter involves a process in which the analytical procedures of science necessarily play a limited role (LINDBLOM, C.E. and WOODHOUSE, E.J. 1993). Much as scientists may wish otherwise, say for a more enlightened public and political sector, action on important societal issues is most commonly driven by immediate perceptions. There is only a limited role for long-term scientific study, for which inadequate resources of time and financial support are available.

Overreliance upon the mathematical predictive approach of the experimental/theoretical sciences has some important consequences for policy in regard to future environmental change. In scientific practice, prediction is a tool used to pose logical consequences of hypotheses that can be subsequently explored through controlled experimentation. Prediction applies to idealized systems, in which the flows of matter, energy, and information can be modeled mathematically. However, policy is driven as much by myth as by method (GIRLING, J. 1993). Popular myth holds prediction to be accurate preknowledge of future events. The myth could conceivably be true, given immutable, invariant lawlike behavior to all nature. However, there is a strong argument that the truth of this myth can never be known via the numerical models employed for prediction. Complete confirmation of such models is precluded both logically and by the incompleteness of human access to the relevant phenomena (ORESKES, N. *et al.* 1994).

Human action may be guided by the conceptual generalizations of science, including model prediction, but its basis lies in perception-based experience (see, e.g., BAKER, V.R. 1994b). Experience involves concrete particulars. To the degree that these stimulate the mind to grasp reality, these real experiences contribute to human understanding. Such experiences can be rather haphazard, and the lack of careful attention accorded them explains many policy failures. However, it is the role of the naturalistic/historical scientist to synthesize experience into a meaningful whole. Herein lies the most important task for the geomorphologist.

As a policy is enacted, it must be informed. That information can include attempts to perceive future events, subject to various uncertainties. However, uncertainty will always be present, a fact essential to the existence of science itself (BAKER, V.R.

1992). Action informed by reality, such as the ranges of geomorphological processes signified in sediments and landforms, must be subject to continual validation against its consequences. It can, nevertheless, be confidently initiated, given the tendency of future conditions to evolve from past ones. By retaining options for adjustment, policy need not be founded upon a bedrock of scientific fact to achieve success. Rather, it can follow as a natural extension of science itself, transforming its basis of perception into the generality of guidance, always subject to the fallibility of the latter's incomplete formulations.

Paleoflood Hydrology

Paleohydrology, the science of ancient water, seeks to discover the past operation of the hydrological cycle. The purpose is to examine reality, particularly through the reconstructed paleoflows of rivers, ancient lake volumes, ground-water fluctuations, etc. In recent years a scientific breakthrough has been achieved in the ability of paleohydrologists to infer very accurate and complete catalogs of ancient, extraordinary floods through scientific study of slackwater deposits and paleostage indicators (SWD-PSI) in stable-boundary fluvial reaches. SWD-PSI paleoflood hydrology is an interdisciplinary breakthrough made possible by recent advances in geomorphology, geochronology, hydraulic flow modeling, and censored-sample maximum likelihood flood-frequency analysis (BAKER, V.R. 1987; BAKER, V.R. *et al.* 1988; STEDINGER, J.R. and BAKER, V.R. 1987).

Variations in the water cycles comprise a key issue, perhaps the most important issue for coping with future global change (GLEICK, P.H. 1993). In water management the "strong causality" characteristic of mechanistic physics does not apply (MATALAS, N.C. *et al.* 1982). Instead, hydrological variability can be viewed as an inherent property of the highly complex hydrological system. Human ability to cope with that variability will depend upon wisdom born of experience on how that system operates over broad scales of time and space. Nevertheless, the change that most concerns humanity is in the future. not the past. Paleohydrologists interpret various indices of past hydrological processes. How can such information help in coping with an uncertain, potentially perilous future? Should not the relevant science for society be focused on that future?

The following example will illustrate the application of retroductive paleohydrological inference to a problem in global change science. The results are preliminary, but they suggest some major phenomena of great potential importance to global habitability. Hypotheses are suggested that will require subsequent confirmation. The important point, however, is that these hypotheses were suggested from discoveries made by a retroductive mode of scientific inquiry.

Tropical rivers have proven to be especially good recorders of SWD-PSI paleoflood hydrology, and excellent sites have been studied in northern Australia (WOHL, E.E., *et al.* 1994) and central India (KALE, V.S. *et al.* 1994). A preliminary synthesis of these data yields some very interesting results. The study sites are located in the monsoonal region *(Fig.1)*, where the largest floods on moderate-sized drainage basins (103 to 105 km^2) result from tropical cyclones embedded within the summer monsoon circulation. Peak paleoflood discharges are found to achieve maxima for their respective drainage areas according to various envelope curves *(Fig. 2)*.

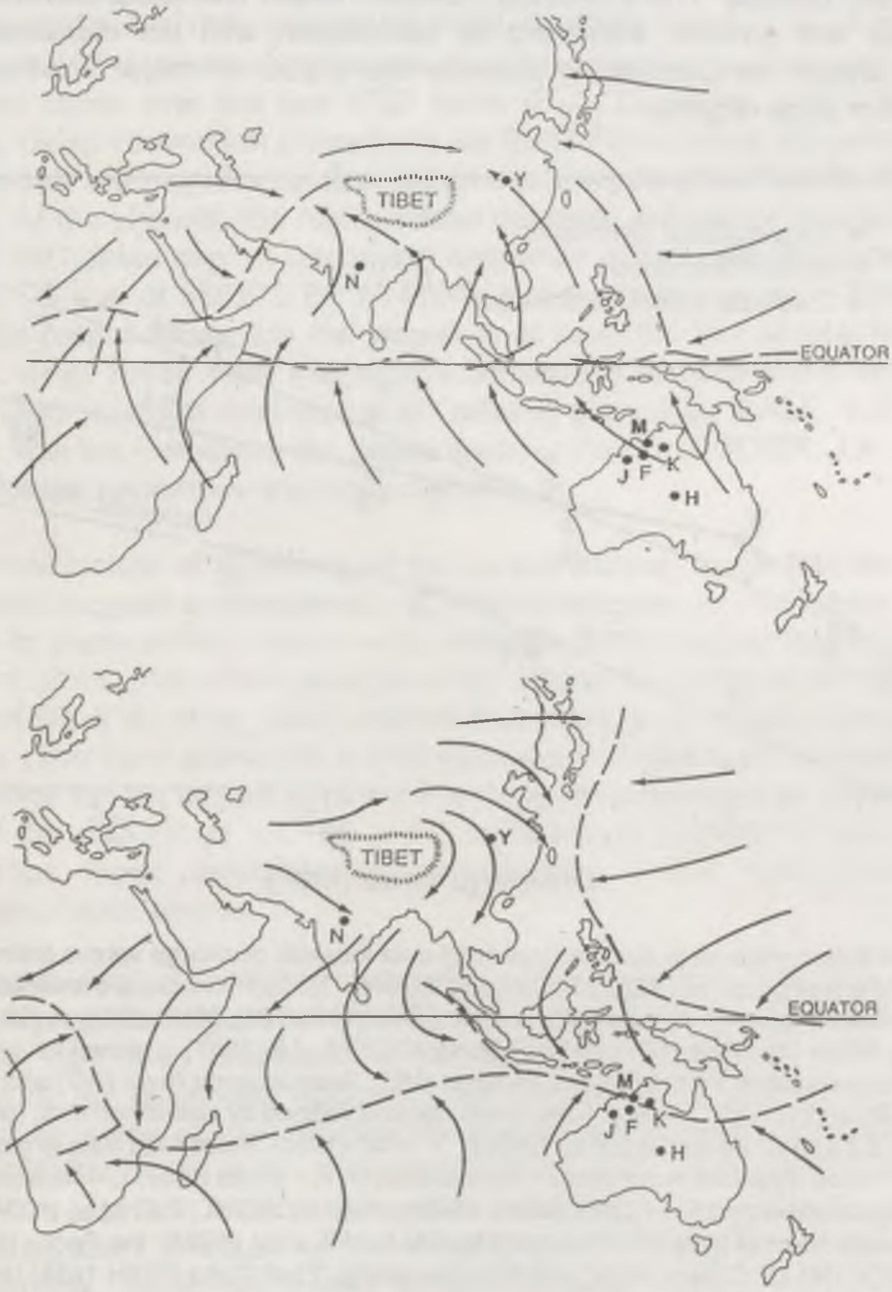

Fig. 1 Maps showing locations of paleoflood study sites (letters correspond to designations in *Fig. 2)* and atmospheric patterns for the Asian summer monsoon (June to September) in the upper map, and the northern Australia summer monsoon (December to March) in the lower map. The arrows show wind patterns and the dashed lines show convergence zones at 700 mb pressure (from BAKER, V.R. 1995)

A recent global climate model (GCM) simulation of enhanced greenhouse conditions demonstrates the likely intensification of the synoptic climatological patterns that produce both anomalously wet and anomalously dry patterns for central Australia (SUPPIAH, R. 1994). The model indicates an enhancement of extremes, including an increase in rainfall intensity and the spatial expansion of heavy rainfall during anomalously wet periods. The simulated monsoon shear line shifts poleward during the anomalous wet periods, indicating its association with the increased rainfall intensities. It should be possible to observe the impact of major flood-generating rainfall in stream gage records.

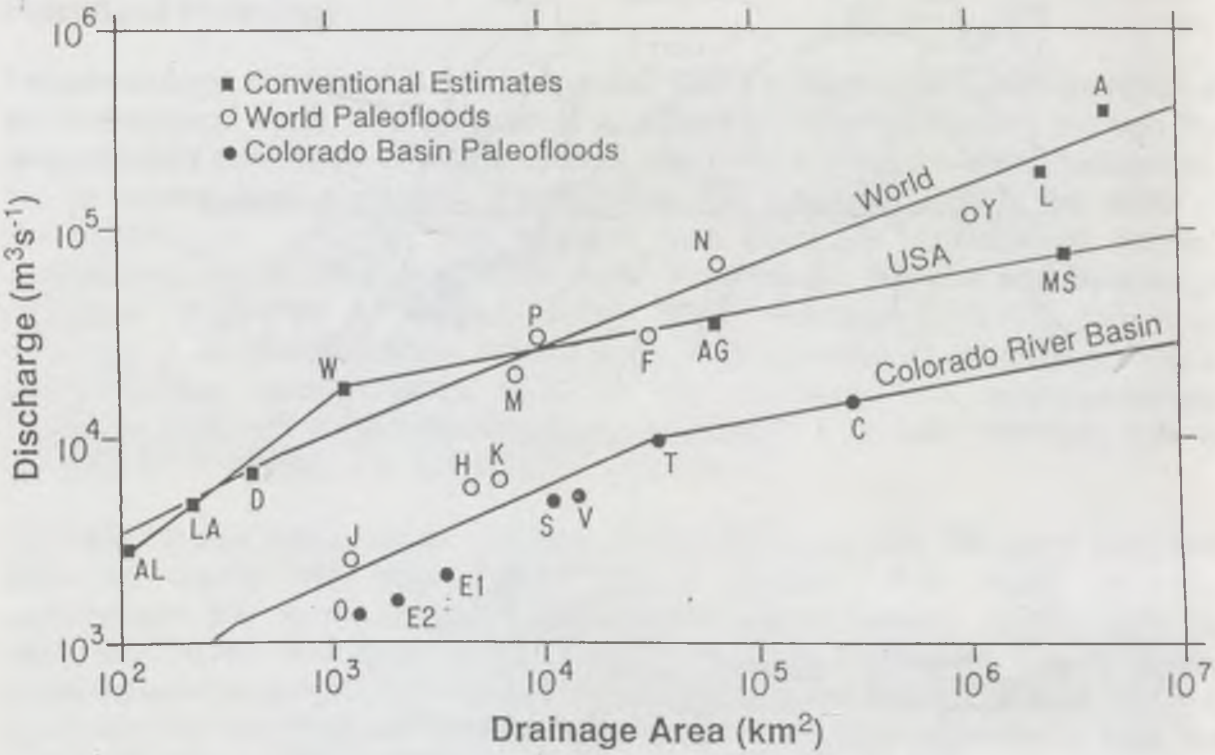

Fig. 2 Paleoflood data compared to conventional flood data for peak discharge versus drainage area. The world envelope curve (RODIER, J.A. and ROCHE, M. 1984) includes conventional data from the following rivers: Amazon (A), Lena (L), Seco Creek (D), Mailtrail Creek (LA) and Hubbard Creek (AL). The U.S. maximum curve (COSTA, J.E. 1987) is shown for comparison. It includes data points for the Mississippi River (MS), Susquehanna River (AG) and West Nueces River (W). The Colorado River basin curve is defined by paleoflood data (points C, T, V, S, E1, E2 and O) as discussed by ENZEL, Y. *et al.* (1993). Paleoflood data of global interest include data from Australia (J = Lennard River, H = Finke River, K = Katherine River, M = Margaret River and F = Fitzroy River), all discussed by WOHL, E.E. *et al.* (1994b); the Narmada River of India (N), discussed by KALE, V.S. *et al.* (1994); the Pecos River (P) of Texas (KOCHEL, R.C. *et al.* 1992) and the Changjiang (Y) of China (SHIH 1985) (from BAKER, V.R.1995)

Unfortunately these provide data that are of too short a duration to detect major changes in the nature of very large, low frequency floods. In contrast, paleoflood SWD-PSI studies in central Australia (BAKER, V.R. *et al.* 1983,1987; PICKUP *et al.*

1988) indicate a 1000-year record of the largest flood events for the Finke River. Of the seven largest floods up to the time of the study (1983), four occurred since 1921 and three since 1967. The trend is not inconsistent with the model simulation.

Results from the Narmada River basin in central India are especially striking. The Narmada is situated such that it is impacted by the most severe rainstorms of the subcontinent (DHAR, O.N. and NANDARGI, S. 1989; KALE, V.S. *et al.* 1994). In a study reach of the central Narmada a complete chronology has been identified for the largest floods over the last 1700 years (ELY, L.L. *et al.* 1993). Hydraulic flow modeling, using convention procedures for SWD-PSI analysis (O'Connor and Webb 1988), reveals the magnitudes associated with the paleoflood events (KALE, V.S. *et al.* 1992). At the site with the highest flood deposits, 4-5 sandy flood units with post-1950 AD 14C dates cap an underlying sequence of 7-10 silty flood deposits with a minimum ^{14}C age of 650±70 BP (A-6631) and a maximum age >1720±185 BP (A-7305). The recent floods are the largest in at least the last several hundred years (ELY, L.L. *et al.* 1993). Their magnitudes correspond to those of the largest events in the last 20-40 years, as recorded at the existing gage sites (KALE, V.S. *et al.* 1994). The peak flow lies just above the global maximum curve (RODIER, J.A. and ROCHE, M.1984) for the respective drainage area *(Fig. 2).*

The regional picture of clustering of the largest tropical floods into the most recent time interval suggest a widespread causative phenomenon. The ability of the SWD-PSI sites to preferentially preserve the deposits of the largest floods, regardless of later event sizes, plus other aspects of the natural recording system (BAKER, V.R. 1989; BAKER, V.R. *et al.* 1987) insures that there is not a selective biasing in the recording. (The latter possibility emphasizes the importance of examining the SWD-PSI evidence for the largest events.) The most likely widespread cause for floods in basins of the size range studied is the incidence of large flood-producing tropical storms. Thus, these preliminary results indicate a possible recent increase in the occurrence of such events.

Clearly more data of this type will be required before a definitive conclusion is possible. A program of global SWD-PSI paleoflood hydrology, with a special focus on the tropics, has been proposed for just this purpose (BAKER, V.R. 1994c). The possibility of an increased frequency for future floods and droughts has been suggested by some model simulations of greenhouse effects (HANSEN, J. *et al.* 1989; GORDON, H.B. *et al.* 1992; WHETTON, P.H. *et al.* 1993). Such changes would have a profound impact upon global habitability. It is therefore essential to test for their realization. Because of the short lengths of conventional records of rainfall and streamflow, especially in the underdeveloped tropics, such testing may be impractical on the time scale necessary to make policy decisions. SWD-PSI paleoflood hydrology presents an opportunity to resolve this policy dilemma.

Conclusions

There is considerable evidence that major environmental changes, particularly those exacerbated by humankind itself (TURNER, B.L. II *et al.* 1990), are threatening the habitability of the planet. In coping with this change many national science programs have placed their emphasis on prediction through idealized conceptual models predicated upon unverifiable assumptions. The problems of human habitability and global environmental change will not be resolved through idealized theories of future climate. As with all issues of action, these problems will be resolved through experience. There is only one scientific source of extensive experience: the indices of real Earth processes in their extant and past spatial complexity. The efforts of geomorphologists may serve a relatively minor role in providing real-world data for the testing of predictive models, However, by far the more important goal of their work is to discover unforeseen workings of the Earth that will require new or revised models (hypotheses) for their explanation. How is this scientific role to be achieved, given the apparent conceptual ascendancy of predictive styles in science and the logical impossibility of verifying/validating those predictions (ORESKES, N. *et al.* 1994)?

In its logic of scientific inference geomorphology may employ three distinct modes. The inductive mode, which infers predictive theory from specific cases, is fundamentally flawed because of unanticipated changes in causative processes. The deductive mode, using mathematical theory to predict specific effects, is logically impeccable, but the logic is our own, imposed on the real world and not practically verifiable against it. The retroductive mode functions to discover nature's own logic, inferring natural causative processes from the indices (signs) of their preserved effects. In practice, the retroductive mode is followed successively by the deductive and inductive. The continuing application of this sequence seeks to converge on truth in the long run.

In the modern science of global environmental change the ability to mathematically simulate change in the idealized "Earth system" has advanced far more rapidly than capabilities to verify such idealizations against change in the real Earth. This has led to an overemphasis on prediction through idealized conceptual models predicated upon unverified assumptions. To understand global environmental change one needs scientific experience of such change as a complement to the conceptualization of that change. One of many ways to make this possible is through the study of indices (signs) of such change. Through its focus on the effects of *realized* processes, geomorphology provides a critical scientific complement to studies that *idealize* hydrological systems in order to predict future change. In studying the experience conveyed to us via natural indices geomorphologists are providing a voice to nature that will be critical for understanding the changes imposed thereupon. For this voice to be effective it must derive from the broadest possible spatial sample of modern environmental change. It must also derive from the record of change in the past. Only then will humankind avoid the fate predicted by philosopher George SANTAYANA in his book *Life of Reason*: "Those who cannot remember the past are condemned to repeat it."

The great Danish physicist Niels BOHR was once asked about the role of physics in regard to the nature of the quantum world that underlies the material reality of our existence. A philosophical proponent of reductive materialistic axiology would answer that the reduced basis of the world system (the quantum world) can readily be scaled up to tell us how the larger world of reality is. BOHR's answer is telling: "It is wrong to think that the task of physics is to find out how nature is. Physics concerns what we can say about nature" (PETERSEN, A. 1985). It can be similarly observed that the task of geomorphology is not so much to find how nature is. Rather, it is the primary task of geomorphology to find what nature can say to us.

Following BOHR's observation, I suspect that it may well be incomplete science to assume that theoretical/predictive earth-system science, following the example of mathematical physics, will ever provide more than an exceptionally clear exposition of what we can say about future global environmental change. For completely satisfying understanding of that change we will need another insight. Though lacking in the logical rigor that we seek to arbitrarily impose on it, nature's own language, interpreted as signs through the naturalistic/historical approach of sciences like geomorphology, provides the needed scientific insight.

To preserve a continually habitable planet through an uncertain future of global environmental change science will need to develop the best possible mathematical models to explain that future. However, just as those models will need to embody the best that scientists can say about the real world, it will also be necessary to explore the real experience of that world for the best that it can say to us. The challenge to geomorphology is for its practitioners to devote just as much effort to exploring the real world of Earth experience as they devote to idealizing the abstract world of Earth systems. By preserving this essential tension, science will advance, and that advancement will most effectively benefit the society that sustains it

Acknowledgments

This paper is AUMIN contribution number 4. My research in paleoflood hydrology has been supported by the U.S. National Science Foundation.

References

ALVAREZ, W. 1991. The gentle art of scientific trespassing: GSA Today, v.1, pp. 29-31, 34.
BAKER, V.R. 1987. Paleoflood hydrology and extraordinary flood events. *Journal of Hydrology,* v. 96, pp. 79-99.
BAKER, V.R. 1989. Magnitude and frequency of paleofloods. In: Floods, their hydrological, sedimentological, and geomorphological implications. Wiley, Chichester, pp. 171-183.

BAKER, V.R. 1992. Tolerance and uncertainty in science and decisionmaking. *Arizona Journal of International and Comparative Law.* v. 9. pp. 253-258.
BAKER, V.R. 1994a. Geological understanding and the changing environment. *Transactions of the Gulf Coast Association of Geological Societies,* v. 44, pp. 13-20.
BAKER, V.R. 1994b. Geomorphological understanding of floods. *Geomorphology,* v. 10, pp. 139-156.
BAKER, V.R. 1994c. Glacial to modern changes in global river fluxes. In: Material fluxes at the surface of the Earth. National Academy Press, Washington, D.C., pp. 86-98.
BAKER, V.R. 1995. Global paleohydrological change. Questiones Geographiae, v. 4.
BAKER, V.R. (in press) The pragmatic roots of American Quaternary geology and geomorphology. *Geomorphology*
BAKER, V.R. and TWIDALE, C.R. 1991. The reenchantment of geomorphology. *Geomorphology,* v. 4. pp. 73-100.
BAKER, V.R., KOCHEL, R.C., PATTON, P.C., and PICKUP, G. 1983. Paleohydrologic analysis of Holocene flood slack-water sediments. *International Association of Sedimentology, Special Publication,* no. 6, pp. 229-239.
BAKER, V.R., PICKUP, G., and WEBB, R.H. 1987. Plaeoflood hydrologic analysis at ungaged sites, central and northern Australia. In: Regional flood frequency analysis. Reidel, Boston, pp. 325-338.
BAKER, V.R., KOCHEL, R.C., and PATTON, P.C. (eds.) 1988. Flood geomorphology. Wiley, New York, 503 p.
BYERLY, R.,Jr., and PIELKE, R.A., Jr. 1995. The changing ecology of United States science. *Science,* v. 269., pp. 1531-1532.
CHAMBERLIN, T.C. 1890. The method of multiple working hypotheses. *Science,* v. 15, pp. 92-96.
CLOOS, H. 1953. Conversation with the Earth. Alfred A. Knopf, New York, 413 p. Committee on Earth Sciences, 1989. Our changing planet: The FY 1990 research plan. U.S. Office of Science and Technology Policy, Federal Coordinating Council on Science, Engineering and Technology, Washington, D.C., 43 p.
Committee on Earth Sciences, 1993. Our changing planet: The FY 1994 U.S. global change research program: U.S. Executive Office of the President, Office of Science and Technology Policy, Washington, D.C., 79 p.
Committee on Global Change, 1990. Research strategies for the global change research program. National Academy Press, Washington, D.C.
DHAR, O.N., and NANDARGI, S. 1989. Distribution of rainfall over different sections of the Narmada basin associated with the highest floods in recent times. *Indian Journal of Power and River Valley Development,* v. 39, pp. 210-214.
Earth System Science Committee, 1988. Earth system science: A closer look. National Aeronautics and Space Administration, Washington, D.C.
ELY, L.L., ENZEL, Y., BAKER, V.R., and KALE, V.S. 1993. A recent increase in the magnitude and frequency of severe floods on the Narmada river, central India. Geological Society of America, Abstracts with Programs, v. 25(6), p. A-396.
GILBERT, G.K. 1886. The inculcation of scientific method by example. *American Journal of Science,* v. 31, pp. 284-299.
GILBERT, G.K. 1896. The origin of hypotheses illustrated by the discussion of a topographic problem. *Science,* v. 3, pp. 1-13.

GIRLING, J. 1993. Myths and politics in western societies: Evaluating the crisis of modernity in the United States, Germany, and Great Britain. Transaction Publishers, New Brunswick, U.S.A. 191 p.

GLEICK, P.H. (ed.) 1993. Water crisis: A guide to the world's fresh water resources. Oxford University Press, Oxford. 473 p.

GOODY, R. 1982. Global change: Impacts on habitability. NASA Jet Propulsion Laboratory Report JPL D-95, Pasadena, California. 15 p.

GORDON, H.B., WHELTON, P.H., PITTOCK, A.B., FOWLER, A.M., and HAYLOCK, M.R. 1992. Simulated changes in daily rainfall intensity due to the enhanced greenhouse effect: Implications for extreme rainfall events. *Climate Dynamics,* v. 8, pp. 83-102.

HANSEN, J., RHIND, D., DEL GENIO, A., LACIS, A., LEBEDEFF, S., PRATHER, M., RUEDY, R., and Karl, T. 1989. Regional greenhouse climate effects. In: Coping with climate change. Climate Institute, Washington, D.C., pp. 68-81.

HOUGHTON, J.T., Jenkins, G., and Ephraums, J.J. 1990. Climate change: The IPCC scientific assessment. Cambridge University Press, Cambridge, 365 p.

International Geopshere-Biosphere Programme, 1992. Global change: Reducing uncertainties. Royal Swedish Academy of Sciences, Stockholm. 40 p.

KALE, V.S., ELY, L.L., ENZEL, Y., and BAKER, V.R. 1994. Geomorphic and hydrologic aspects of monsoon floods on the Narmada and Tapi rivers in central India. *Geomorphology,* v. 10, pp. 157-168.

KALE, V.S., MISHRA, S., ENZEL, Y., ELY, L., BAKER, V.R., and RAJAGURU, S.N. 1992. Geomorphic investigations of floods in central Narmada Basin, India. In: First National Symposium on Environmental Hydraulics. C.W.P.R.S., Pune, India. pp. 211-220.

KELLER, E.F. 1985. Reflections on gender and science. Yale University Press, New Haven, 189 p.

KUHN, T.S. 1962. The structure of scientific revolutions. University of Chicago Press, Chicago. 210 p.

LAUDAN, L. 1980. Why was the logic of discovery abandoned? In: Scientific discovery, logic and rationality. Reidel, Dordrecht. pp. 173-183.

LINDBLOM, C.E., and WOODHOUSE, E.J. 1993. The policy-making process. Prentice-Hall, New Jersey, 122 p.

MAHLMANN, J.D. 1989. Mathematical modelling of greenhouse warming: How much do we need to know? In: Global change and our common future. National Academy Press, Washington, D.C., pp. 62-72.

MATALAS, N.C., LANDWEHR, J., and WOLMAN, M.G. 1982. Prediction in water management. In: Scientific basis for water resource management. National Academy Press, Washington, D.C. pp. 109-117.

MOLNIA, B.F. 1994. Our changing planet: Global change revisited. *GSA Today,* v. 4, p. 7. O'Connor, J.E., and Webb, R.H. 1988. Hydraulic modelling for paleoflood analysis. In: Flood geomorphology. Wiley, New York. pp. 393-402.

ORESKES, N., SHRADER-FRECHETTE, K., and BERLITZ, K. 1994. Verification, validation, and confirmation of numerical models in the Earth sciences. *Science,* v. 263, pp. 641-646.

PERRY, J.S. 1991. Global change: From rhetoric to reality. *Reviews of Geophysics* (supplement). U.S. National Report to International Union of Geodesy and Geophysics. pp. 39-45.

PETERSEN, A. 1985. The philosophy of Niels Bohr. In: Niels Bohr: A centenary volume. Harvard University Press, Cambridge. pp. 299-310.

PICKUP, G., ALLAN, G., and BAKER, V.R., 1988. History, paleochannels and paleofloods of the Finke River, central Australia. In: Fluvial geomorphology of Australia. Academic Press, Australia, Sydney, pp. 177-200.

RHOADS, B.L., and THORN, C.E. 1993. Geomorphology as a science: The role of theory. *Geomorphology,* v. 6, pp. 287-307.

RODIER, J.A., and ROCHE, M. 1984. World catalogue of maximum observed floods: IAHS-AISH Publication, no 143. pp. 1-354.

SCHLESINGER, M.E., and JIANG, X. 1991. Revised projection of future greenhouse warming. *Nature,* v. 350. p. 219.

SHORT, N.M., and BLAIR, R.W., Jr. 1986. Geomorphology from space: A global overview of regional landforms. NASA Special Publication 486, Washington, D.C. 717 p.

STEDINGER, J.R., and BAKER, V.R. 1987. Surface water hydrology: Historical and paleoflood information. *Reviews of Geophysics,* v. 25. pp. 119-124.

SUPPIAH, R. 1994. Synoptic aspects of wet and dry conditions in central Australia: Observations and GCM simulations for $1xCO_2$ and $2xCO_2$ conditions. *Climate Dynamics,* v. 10, pp. 395-405.

THOMAS, W.L., Jr. 1956. Man's role in changing the face of the Earth. University of Chicago Press, Chicago. 1193 p.

TURNER, B.L. II, CLARK, W.C., KATES, R.W., RICHARDS, J.F., MATTHEWS, J.T., and MEYER, W.B. 1990. The Earth as transformed by human action: Global and regional changes in the biosphere over the past 300 years. Cambridge University Press. Cambridge. 713 p.

VON ENGELHARDT, W., and ZIMMERMANN, J. 1988. Theory of Earth science. Cambridge University Press, Cambridge, 381 p.

WEINBERG, A.M. 1970. The axiology of science. *American Scientist*, v. 58, pp. 612-617.

WHETTON, P.H., FOWLER, A.M., HAYLOCK, M.R., and PITTOCK, A.B. 1993. Implications of climate change due to the enhanced greenhouse effect on floods and droughts in Australia. *Climatic Change,* v. 25, pp. 289-317.

WIGNER, E. 1964. Events, laws of nature, and invariance principles. *Science,* v. 145. pp. 995-999.

WOHL, E.E., FUERTSCH, S.J., and BAKER, V.R. 1994. Sedimentary records of late Holocene floods along the Fitzroy and Margaret rivers, Western Australia. *Australian Journal of Earth Sciences,* v. 41, pp. 273-280.

ZIMAN, J. 1978. Reliable knowledge: An explanation of the grounds for belief in science. Cambridge University Press, Cambridge, 197 p.

Human-Induced Environmental Changes in Central Europe

DEMEK, Jaromír
Department of Geography, Palacký University of Olomouc
Svobody 26, 771 46 Olomouc, Czech Republic

Introduction

In the past 7000 years the environment of Central Europe has been dramatically changed by the human activity. Environmental quality, changing over time, has influenced both the type and intensity of natural geomorphological processes and, due to their direct relations and feedbacks, the entire relief.

The Clearing of Woodlands and Farming

Perhaps the most important single factor in the evolution of the Central European environment has been the clearing of the wood which once clothed almost all of Europe. Even the dry Alföld (Great Hungarian Plain), noted for its steppe-like character, is shown in vegetation reconstructions to have been originally wooded. In Central Europe the temperate forest zone is dominated by oak, mixed with a variety of other deciduous trees including beech, but giving way to conifers in the highlands and mountains.

The presence of woodland, and the effort to use it or subdue it, has been a constant motive in changing of environment for centuries. The attack began with the advent of agriculture in the Neolithic and, with the gradual population growth, wooded areas have been given way to pastures and arable lands. The forests were cleared partly by felling and partly by fire. However, the clearing has not been a continuous or sustained process, for at times, the forest has reasserted itself and extended over the previously cleared areas. Nor has the clearing been complete, for substantial tracts of wooded areas still remain.

Landscapes cleared during the advent of agriculture are called old-settled landscapes. Six thousand years of ploughing and farming have left clear evidence of accelerated soil erosion in the form of correlated deposits, soil accumulations and modified topography. All the so-called steppe areas of Central Europe belong to these old-settled landscapes, therefore, we are unable to delimitate the original non-forested areas at the time of the arrival of the Neolithic people.

In old-settled landscapes Holocene black soils, thick accumulations of soil sediments and floodplain loams are also preserved. Accelerated soil erosion caused accumulation of soil sediments in dells, dry valleys and at footslopes. Originally, well- developed soil types degraded into truncated soil profiles. Commonly this process has gone so far that where there was once a well developed climax soil we see the initial stages only of corresponding soil type, eventually skeletal soil.

It was not until the Middle Ages that the main outline of the clearing of this dense Central European woodland was sketched, and the story of that clearing is much better documented here than elsewhere in Europe (DARBY, H.C. 1958, p. 183). These areas are called young-settled landscapes, where deforestation., ploughing and farming followed by the acceleration of natural geomorphologic processes have taken place only in the last 2000 years. But it is necessary to keep in mind that young-settled landscapes are higher regions (highlands or mountains) and more humid than old ones. Clearing, therefore, means larger changes in the environment than in the most old-settled landscapes. Evidence of these changes are several layers of sandy-loam deposits in the floodplains of Central European rivers and gullies of different forms, lengths and depths.

Forest clearing was promoted by the establishment of entirely new settlements. After 800 AD, in German valleys between the Neckar and the Main rivers there appeared so called forest villages *(Waldhufendorf)*. In the 11th and 12th centuries this type of settlement spread into the highlands and the mountains of the Bohemian Highlands and of Poland. Younger still is the Valachian colonisation (15th century) which changed the environment of the montainous regions in the Western Carpathians. Scattered houses were spread through the forest in small clearings (so-called *kopanice* in Slovakia). In the existing villages there was also a widespread extension of both pastures and arable land with new fields brought into being alongside the old ones. Many *Hohlwege* mark the old access roads to these fields. A lot of them have changed over the centuries into different types of gully locally known as *balka, Tolke, Sieke*, etc. (HEMPEL, L. 1954). The struggle has left a mark, often upon the type and intensity of geomorphological processes, and invariably upon the general character of the landscape. Besides accelerating intense soil erosion on ploughed slopes, the eroded soils filled river beds and valley bottoms. Aggradation caused regular inundation of floodplains. Houses, villages and towns had to move to higher places (mostly to river terraces). Later this called for the construction of river embankments and the drainage of backswamps.

In most regions of Central Europe the progress of agriculture had certainly passed its maximum by 1300, and the great age of expanding arable land was succeeded by one of stagnation and contraction. But demands made upon wood as construction material, fuel, charcoal and timber for mining increased with the growing Central European population. The decline then was especially severe during the Thirty Years' War (1618-1648). Abandoned holdings and deserted villages were to be found in Germany (called *Wüstungen*), Austria, Poland and the Czech Republic. It is diffucult to say to what an extent the woods advanced upon the untilled fields and unused pastures, but there is no doubt that they did in many places. Traces of cultivation and dwelling can be found in the wooded areas of Central Europe even today.

Looking at Central Europe as a whole in the 19th and 20th centuries, it is surprising that despite varied demands upon wood and the long centuries of exploitation, so much forest cover still remained (27 per cent of Germany, 23 per cent of Poland, 33 per cent of the Czech Republic, 37 per cent of Slovakia, 37 per cent of Austria, 13,6 per cent of Hungary; DIETRICH, B.F.A. 1928, PÉCSI, M. and SÁRFALVI, B. 1962).

In our century farming influenced of the Central European environment from further aspects. The use of large amounts of fertilisers and biocides led to changes in the chemical composition of groundwater. The geomorphological consequences of these changes are most obvious in the karst areas. In the Moravian Karst (Czech Republic) these changes manifested itself in both the corrosion and dissolution of dripstones in caves.

Urbanisation

A second factor in the evolution of the Central European environment has been the transition from a rural to an urban landscape due to the growth of villages or mining settlements into towns, and the foundation of new towns "on green meadows" in the 11th and 12th centuries.

The process of urbanisation has become more intense since the beginning of the 19th century in connection with the Industrial Revolution. Urbanisation has completely changed the original rural landscape into an urban landscape over large parts of the region. In the 20th century many cities formed urban agglomerations with a characteristic landscape structure. Landforms within the urban settlements have been substantially changed due to surface levelling and aggradation activities (such as sanitary landfill), the climate modified, runoff conditions altered since large surfaces were built up or sealed in other ways, soils and biota degraded or eliminated.

Cities as anthropogenic deserts

Due to the urban climate mean air temperature in cities is higher than in the surrounding open landscape. Differences between these two environments generally are ca. 0.5 to 2.5°C. In fact, the differences in temperatures between the city centres and the open landscape might reach 10°C (eg. in Brno, Czech Republic it is 9.5°C). There are two contributing factors: the large surfaces of roofs, the sealed surfaces (concrete, asphalt, etc.) of roads, squares and parking places cause high temperatures near surface, and consequently a rapid evaporation of rain water and dew moisture. This is coupled with a rapid runoff into the city's sewerage system. These processes result in lower air humidity and edaphic aridiry. The atmosphere near the surface is also polluted by emissions (eg. nitrogen oxides from cars, sulphur dioxide from local heating - *Fig. 1*). Evidence of desert conditions are salt crystals (halite, anhydrite) on sculptures, walls and microenvironments that are sheltered from rain. Their surfaces are coated by a veneer of loosened-up material composed of small grains of stone or other building materials held together by salts. Relatively hard building materials are completely broken down into their component particles by either soaking or spraying them with a salt solution and from the consequent crystallisation of salts in their interstices. These processes are accelerated by the use of salt in the city for melting snow on roads and sidewalks during the winter. The cavernous weathering of city surfaces is its most distinctive feature.

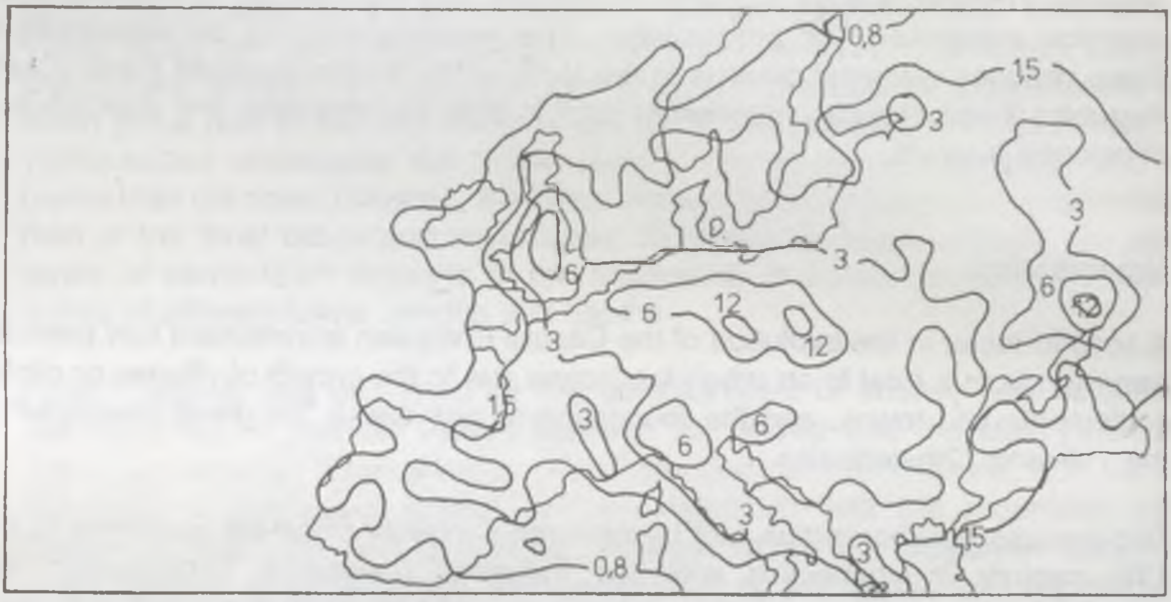

Fig. 1 Sulphur deposition over Europe (annual values in grams per square metre)

Industrialisation

In most Central European countries Industrial Revolution started in the early 19th century. During this period the growth of industrial production was accompanied by the development of the mining industry (eg. coal mining) and transport (construction of a European railway network). The advancement of mining and industry caused profound changes in relief, especially in the industrial regions (Ruhr and Saxonia in Germany, Silesia in Poland, Northwest Bohemia in the Czech Republic, etc.). Open-cast mining (eg. brown coal, iron ore) devastated large areas. Industrial emissions caused air, water pollution and soil contamination. All countries of Central Europe contribute to pollution to a lesser or greater extent. Due to transboundary flow of pollutants other countries have also been affected.

Air pollution, acid rain and accelerated weathering

Many power stations in Central Europe burn coal with high sulphur content. It is also used in factories and for domestic heating (eg. in the Czech Republic). A map of sulphur deposition over Central Europe shows large areas with annual values of 12 grams per square metre.

All Central Europe is seriously affected by acid rains which have been accelerating weathering. Direct observation of accelerated weathering in the landscape is difficult. There are few data eg. the higher rate of pit formation in granite bedrock due to weathering for the last 20 years. Indirect pedological data show pH values of 2.7 for some soils in mountains of Central Europe built of granite. Moreover, the higher heavy metal content in groundwater can be interpreted as a phenomenon associated with accelerated weathering. Traces of accelerated weathering are to be found in Central European cities and towns where sculptures, walls of buildings and old stone bridges (constructed eg. of sandstones) have been affected over the past 20 years. Features of accelerated honeycomb weathering have been observed in walls built of Cretaceous or Flysch sandstones with calcium carbonate cement.

Flash-floods

The collectivisation in agriculture in the former socialist countries of Central Europe have led to the formation of large fields on long slopes. During the past 20 years new geomorphological processes called flash-floods have been described. A typical feature of flash-floods is that they are restricted to catchment basins with predominantly arable land where on the slightly inclined but long slopes cereals, corn (maize), potatoes and sugarbeet are grown. After heavy rains (over 50 mm per hour) of short duration (usually some tens of minutes) over a small area (some ten of square kilometre) extreme high runoff values occur. The slope length plays a most important part in the formation of runoff during flash-floods. The high velocity of water sweeping down the long slopes minimizes infiltration. Flash-floods intensify soil erosion, the accumulation of large amount of the removed material at footslopes and in river beds, causing disastrous damage to properties and in some cases being responsible for casualties.

Conclusions

The environment of Central Europe has overcome a dramatic change over the past 7000 years. Nowadays human activities are the decisive factors responsible for the geomorphic processes changing the relief component of the environment. A typical feature is the acceleration of natural geomorphic evolution (eg. weathering, soil erosion, karst processes, etc.) through deforestation, farming, industrialisation, urbanisation and the related air and water pollution (acid rains, chemical changes in surface and subsurface waters). New geomorphic processes and environments have developed (eg. cities as anthropogenic deserts). Recently the relief has been changed dramatically by technogenic processes and with the appearance of man-made landforms as highly frequent phenomena in Central Europe.

Acknowledgement

The author is indebted to Sandra Sweeney, Palacký University of Olomouc, for the linguistic editing and for valuable advice.

References

DARBY, H.C. 1958. The Clearing of the Woodland in Europe. In: THOMAS, W.L.: Man's Role in Changing the Face of the Earth. The University of Chicago Press, Chicago, Illinois. pp. 183-216.

DIETRICH, B.F.A. 1928. European Forests and their Utili sation. Economic Geography, IV., London. pp. 140-158.

HEMPEL, L. 1954. Tolken und Sieke - ein Vergleich. *Erdkunde*, 8, Bonn. pp. 198-202.

LIEDTKE, H. and MARCINEK, J. (eds 1994). Physische Geographie Deutschlands. Justus Perthes Verlag, Gotha, 559 p.

NIR, D. 1983. Man, a Geomorphological Agent. Keter, Jerusalem & Reidel, Dordrecht. 165 p.

PÉCSI, M. and SÁRFALVI, B. 1962. Die Geographie Ungarns. Corvina, Budapest. 399 p.

Holocene Changes in Fluvial Dynamics: Examples from Southwest Germany

BARSCH, Dietrich, SCHUKRAFT, Gerd, and SCHULTE, Achim
Institute of Geography, University of Heidelberg
Im Neuenheimer Feld 348, D-69 120 Heidelberg, Germany

Introduction

Rivers are sometimes only seen as systems which are responsible for flooding larger areas. Thus, the discussion of their dynamics is often restricted on questions about the variation of discharge. This limited view can not be accepted in geomorphology. The dynamcs of rivers comprises all the work they actually do including erosion, transport and sedimentation, as well as channel adjustment which varies (naturally) with the seasonal and annual variation of discharge. In many cases, the information on the present-day dynamics of rivers is poor. The variation in fluvial dynamics of a river system in time (caused by changes in the basin parameters, in climate or in human activity) is often only qualitatively known.

During the last years, data has been collected on the fluvial dynamics in South-West Germany (cf. BARSCH, D. *et al.* 1989, 1993, 1994a, 1994b; BAADE, J. *et al.* 1992, BAADE, J. 1994, SCHUKRAFT, G. in prep., SCHULTE, A. 1995). Studies were undertaken in the basin of the Elsenz (southwest of Heidelberg) and partly at the Neckar *(Fig. 1)*.

Present-day transport in the Elsenz River

The sediments transported by the Elsenz today are silt, derived from soil erosion of the loess, which covers the catchment (maximum thickness more than 15 m). Bankfull discharge of the lower Elsenz (at Bammental) occurs once every 2.6 years (1970-90). In the period before 1970 (ie. 1930-70), the discharge was recorded once every 1.3 years. If only the wetter years 1978-90 are considered, bankfull discharge is observed once in 2 years (SCHULTE, A. 1995: p. 156).

Two flood events and their sediment transport characteristics will be discussed. The flood of March 1988 is a 10 years event (over bankfull discharge, maximum 90 $m^3 s^{-1}$ at the Hollmuth gauge); the flood of Febrary 1990 is about a 5 years event (bankfull discharge, maximum 75 $m^3 s^{-1}$). The sediment transport values in suspension are given in *Fig. 2* (SCHULTE, A. 1995: 161). In general, it can be said, that a five years event transports about 15,000 t a^{-1} out of the catchment; a ten years event about 40,000 t a^{-1} (SCHULTE, A. 1995: p. 162, cf. FLÜGEL, W.A. 1982).

Fig. 1 The investigation area of the Elsenz catchment and the lower course of the Neckar river (gauges and sampling sites are marked)

From the sediment transported in suspension by the floods of March 1988 and February 1990, the figures given in table 1 can be used to calculate the sediment delivery from the channel. The balances of 29,000 t (March 1988) and 11,000 t (February 1990) must have been eroded in the channel itself. Measurements in the channel and a comparison with measurements completed in the last century show no measurable changes and a stable sequence of pools and riffles. The sediments are, therefore, supposed to be a liquid mud, not detectable by echo soundings, but nontheless present and can be sampled by core freezing. The sediment accumulates in the pools and behind the weirs during local events. Small storms create soil erosion and especially gully erosion in the thalwegs above the upper ends of the channels (Tiefenlinienerosion), but not a flood which effects the whole system. This is a scale problem: The micro-scale events (local storms) are loading the system, the meso-scale event (as bankfull discharge in a 500 km^2 catchment) flushes the material stored in the channel. This is supported by the lapse time between the maxima of sediment concentration and discharge. At the Hollmuth gauge (output Elsenz catchment, see *Fig. 1 and* 2) the concentration maximum occurs 9 h before the peak discharchge. There exist additional indications that the channel reach, in which the liquid mud is stored, is only 13 km long (below the gauges at the lower Schwarzbach and at Meckesheim).

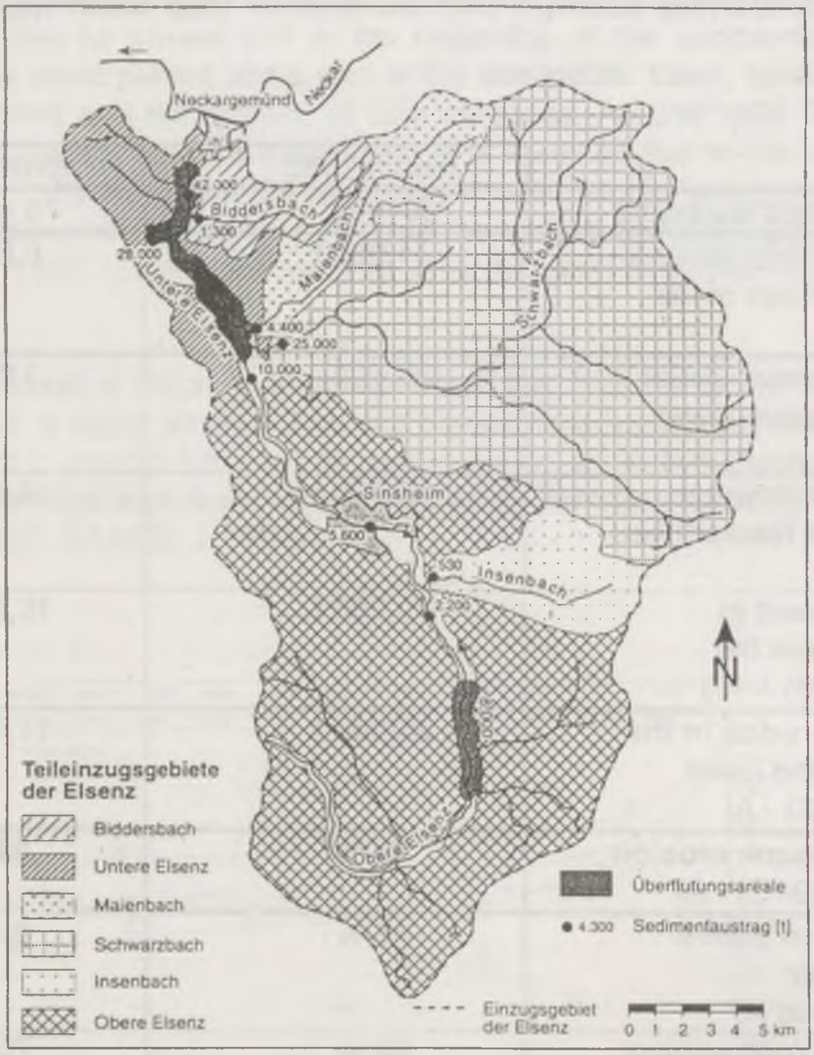

Fig. 2 Suspension load and sediment deposits at the Elsenz catchment during the 10-year flood in March 1988 (SCHULTE, A. 1995)

Present-day transport in the Neckar River

During the flood events of March 1988, February 1990, December 1993 and April 1994 the transport in suspension by the Neckar at Heidelberg (basin area ca 14,000 km^2) was sampled. Maximum discharge was 1950 m^3s^{-1}, 2310 m^3s^{-1}, 2650 m^3s^{-1}, 2380 m^3s^{-1}, respectively; the recurrence interval is 20, 50, 100 and 50 years respectively. The sediment load during each event has been calculated to 1,200,000 tons, 510,000 tons, 700,000 tons and 350,000 tons.

The maximum concentration of suspended sediments is always measured before the maximum discharge. This indicates also for the bigger system that part of the sediment must have been stored as liquid mud in the channel. The figures demonstrate that the storage has been exhausted and the 100 year flood event in

1993 transported less sediment than the flood of 1988 which was only a 20 year event.

	March 1988	February 1990
Maximum flood discharge	90 m^3s^{-1}	75 m^3s^{-1}
Input by the tributaries to the lower course of the Elsenz (A)	**41,000 t**	**8,800 t**
Output by accumulation on the floodplain lower course (B)	28,000 t	3,800 t
Output from drainage area into the Neckar river (C)	42,000 t	16,000 t
Total sediment in transport from the catchment (B) + (C)	**70,000 t**	**19,800 t**
Sediment eroded in the channel of the lower Elsenz [(B+C) - A]	**29,000 t**	**11,000 t**
Amount of bank erosion (X) = % of [(B+C) - A]	**40 %**	**55 %**
Bank erosion above middle water (percentage of X)	40 %	30 %
Liquid mud (percentage of X)	60 %	70 %

Table 1 Measured flood discharge, suspended load, bank erosion and liquid mud at the Elsenz river during the floods of March 1988 and February 1990 (SCHULTE, A. 1995)

Changes in Holocene transports in the catchment of the Elsenz

A very important archive on the Holocene fluvial dynamics is presented in the floodplain deposit of the river Elsenz and its tributaries. On top of sandy-gravelly deposits lie 4 m of fine-grained alluvium (Elsenz) increasing up to 7 m in the tributaries. The sediments are derived from the well developed loess cover, and they are of mid and late Holocene age. The sedimentation is a consequence of the soil erosion caused by neolithic farmers (cf. BARSCH, D. *et al.* 1993, LANG, A. 1995). It was strong enough to force a change in river behaviour from a sand-gravel dominated channel, which was inherited from periglacial times, to a pure silt system in all parts of the basin of the Elsenz. The silt dynamics is still dominant today. It can be shown that the intensity of the silt sedimentation increased from 5000 BP to the present. This can be demonstrated by a graph *(Fig.3)*, which shows the development of the floodplain at three different locations.

It is not yet possible to isolate single events in the cores through the flood plain deposits, but it can be shown that in the beginning of the sedimentation of soil erosion products, sand played some part in the sediments. Later, sand grain sizes are no longer found and the amount of clay increases. Around 1000 AD, the clay fraction in the sediments reaches a maximum. It is assumed that at this time the clay rich B horizons of the lessivées (Parabraunerde) were eroded in most parts of the catchment and the unweathered loess formed the surface of most slopes. Thus, the sediments after 1000 AD present more or less the grain size distribution of pure loess.

Soil erosion still plays a major geomorphic role in this area today, even if the input into the channels is much smaller than soil particle movement measured on fields and field plots. It is around 1.0 t ha^{-1} a^{-1} and 1.6 t $ha^{-1}a^{-1}$ in two Elsenz tributaries, and it is mainly derived from linear erosion (gullying, Tiefenlinienerosion; cf. BAADE, J. *et al.* 1992, 1993, BAADE, J. 1994).

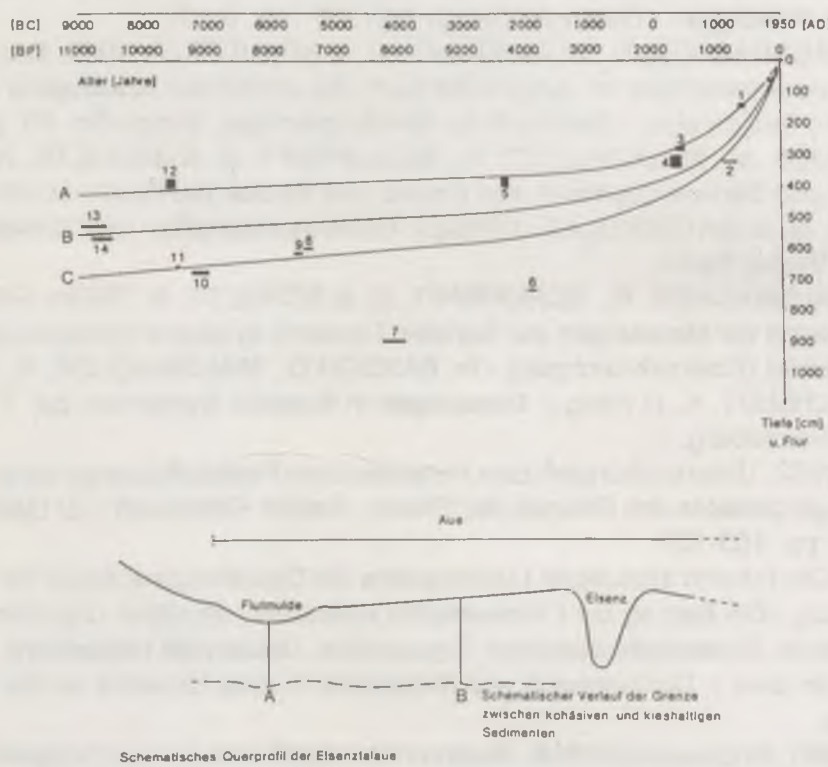

Fig. 3 Rate of sedimentation at the floodplain of the Elsenz during Holocene (ages in ^{14}C- cal. BP) (BARSCH, D. *et al.* 1993)

Conclusion

It is assumed that not only the sedimentation increased since 5000 BP, but also the fluvial dynamics, which caused intense flooding of the valley bottom. Today, the deep channel of the Elsenz prevents flooding. At the moment, a trend to bank erosion and channel widening is observed.

References

BAADE, J. 1994. Geländeexperiment zur Verminderung des Schwebstoffaufkommens in landwirtschaftlichen Einzugsgebieten. - Heidelberger Geographische Arbeiten 95.

BAADE, J.; BARSCH, D.; MÄUSBACHER, R. & SCHUKRAFT, G. 1992. Sanierung diffuser und linearer Schwebstoffquellen in der Agrarlandschaft. - Bericht über das 3. Statuskoll. 18./19.02.92 in Karlsruhe. KfK-PWAB-Bericht 13: pp.149-161.

BAADE, J.; BARSCH, D.; MÄUSBACHER, R. & SCHUKRAFT, G. 1993. Sediment yield and sediment retention in a small loess-covered catchment in SW Germany.- Z. Geomorph. N.F., Suppl. 92. pp. 217-230.

BARSCH, D.; MÄUSBACHER, R.; SCHUKRAFT, G. & SCHULTE, A. 1989. Beiträge zur aktuellen fluvialen Dynamik in einem Einzugsgebiet mittlerer Größe am Beispiel der Elsenz im Kraichgau. - Göttinger Geogr. Abh. 86. pp. 9 - 31.

BARSCH, D., MÄUSBACHER, R., SCHUKRAFT, G. & SCHULTE, A. 1993. Die Änderungen des Naturraumpotentials im Jungneolithikum des nördlichen Kraichgaus dokumentiert in fluvialen Sedimenten.- Zeitschrift für Geomorphologie, Suppl.-Bd. 93: pp.175-187.

BARSCH, D., GUDE, M., MÄUSBACHER, R., SCHUKRAFT, G. & SCHULTE, A. 1994a. Feststoff-und Sedimentdynamik von Elsenz und Neckar bei Hochwasserabfluß. In: MÜLLER, G. & MATSCHULAT, J.(Hrsg.): Geowissenschaften und Umwelt: 85-94. Springer Verlag Berlin.

BARSCH, D., MÄUSBACHER, R., SCHUKRAFT, G. & SCHULTE, A. 1994b. Erfahrungen und Probleme bei Messungen zur fluvialen Dynamik in einem mesoskaligen Einzugsgebiet (Elsenz/Kraichgau).- In: BARSCH D., MÄUSBACHER, R., PÖRTGE, K.-H.& SCHMIDT, K.-H.(Hrsg.): Messungen in fluvialen Systemen: pp. 71-100. Springer Heidelberg.

FLÜGEL, W.A. 1982. Untersuchungen zum mineralischen Feststoffaustrag eines Lößeinzugs-gebietes am Beispiel der Elsenz, Kleiner Odenwald.- Z. Geomorph. N.F., Suppl.43. pp. 103-120.

LANG, A. 1995. Die Infrarot stimulierte Lumineszens als Datierungsmethode für holozäne Lößderivate.- Ein Beitrag zur Chronometrie kolluvialer, alluvialer und limnischer Sedimente in Südwestdeutschland. Dissertation, Universität Heidelberg.

SCHUKAFT, G. (in prep.). Die holozäne und historische fluviale Dynamik an der Elsenz im Kraichgau.

SCHULTE, A. 1995. Hochwasserabfluß, Sedimenttransport und Gerinnebettgestaltung an der Elsenz im Kraichgau. Heidelberger Geographische Arbeiten 98.

SUZUKI