GEOMORPHOLOGY

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Geomorphology

Richard A. Marston

Geomorphology is the science that studies landforms and soils in a historical and functional context, including morphological elements, physical and chemical processes, and materials of composition. If training in geography provides a special opportunity for making contributions to geomorphology, it is in studies that examine interactions between geomorphic and related biophysical systems, human interference in geomorphic systems, and predictive spatial (dynamic and statistical) modeling of morphological, cascading, and process-response systems in geomorphology. These opportunities closely parallel the "integration," "synthesis," and "prediction," respectively, described by Orme (1985) as the preferred goals of the geographer's science.

This chapter describes the impact of American geographers on the discipline of geomorphology. This is accomplished through:

- inventory of research in geomorphology published by American geographers;
- citation of selected works by American geographers in areas of geomorphology where a geographer's perspective has proved useful in the development of fundamental concepts; and
- discussion of the participation by geographers in professional geomorphological organizations.

This is not intended as a historical review of geographical geomorphology, but rather a report on the current aims, methods, and central ideas, as well as possible future directions that geographers may pursue. Trends in the studies of soils and physical environments of the Quaternary are included, reflecting the natural ties of these fields to geomorphology. American geographers in geomorphology are defined as those who practice their profession in the United States, a definition that includes approximately 5% of the total AAG membership and 21% of all practicing geomorphologists in the United States.[1]

[1]Of the 1435 members in the Quaternary Geology and Geomorphology Division of the GSA (October 1987 data), approximately 8% are foreign-based, and 4% are geographers, according to the current chair of the Division. Of the 268 members in the Geomorphology Specialty Group of the AAG (May 1987 data), 3.4% are foreign-based, and 4.9% are geologists. Students comprise approximately 20% of the membership of both groups. Another 63 American geographers claim geomorphology as a specialty in the *Guide to Departments of Geography in the United States and Canada, 1987–88*. Therefore, geologists number 976 (79.4%) and geographers number 253 (20.6%) of the total number of 1229 geomorphologists practicing in the U.S. When foreign-based members of each group are included, geologists and geographers comprise 80.6% and 19.4%, respectively, of the total number of geomorphologists belonging to either the GSA or AAG.

Separating the contributions of American geographers from the contributions of geomorphologists having backgrounds other than geography, and from geographers who practice geomorphology outside the U.S., is a task that has not been pursued in the literature. This is a separation that is somewhat artificial in light of the increasing interaction between geography and other disciplines, and the increasing opportunities for exchange of information between colleagues in countries worldwide. Indeed, Vitek (1988) argued that institutions (professional societies, universities, and informal groups) and the transfer of enthusiasm and ideas by influential practitioners have become more important factors in the advance of the discipline than one's particular field of training.

A significant portion of the research by American geographers in geomorphology is concerned with topics that are not geographical in the sense of integration, synthesis, and predictive spatial modeling. Nevertheless, it is critical to solidifying the position of geomorphology within geography to identify a sample of those works that pursue the integration-synthesis-prediction themes, among other important contributions.

A number of manuscripts have been published recently that address various aspects of the field: the status of geomorphology (Pitty 1982, 1985; Hart 1986; Bashenina et al. 1987; Cooke 1987; Tricart 1987); the function of geomorphology within physical geography (Gregory 1985); and the position of geomorphology (and other subfields) in geography (Johnston 1985). Baker (1986) and Ritter (1988) provide the perspective of American geologists on the nature of geomorphology. Walker and Orme (1986) offer some clues as to the nature of geomorphology at an international level in the 1980s, based on themes evident in the First International Conference on Geomorphology. These reviews all paint an optimistic future for the discipline of geomorphology, but the influence of American geographers is not apparent.

The themes, developments, potentials, and needs of geomorphology in geography were stated at the beginning of the decade by Graf and his colleagues, although the contributions by American geographers were not singled out. Graf et al. (1980) applauded the new pluralism in geomorphology and pointed out the following major developments, all of which remain valid late in the decade:

> . . . an increased dependence on field research (an old tradition revisited), more realistic expectations from research tools, a resurgence of interest in man-land relationships with a concomitant dependence on the historical approach, an expanded appreciation of the hydrologic cycle, a reinvestigation of morphogenetic regions, new interest in planetary surfaces other than the earth's, more detailed investigations of event magnitude and frequency, and an involvement with applied problems.

In another key review of the discipline, Graf (1984) reported on the uneven distribution of field localities for major research efforts in American geomorphology since 1817. He warned of the dangers of applying geomorphic theories developed from research in one region to investigations in another region without recognition of and adjustment for this spatial bias, particularly with respect to mountain regions and fluvial systems.

Costa and Graf (1984) examined the numbers, professional affiliations, publications and locations of geomorphologists and Quaternary geologists in the United States, a review that provided the first statement of the relative contribution of geographers to geomorphology.

PUBLICATIONS

An update of the work by Costa and Graf (1984) reveals the number of geomorphology papers published in the period 1976–86, in refereed journals, printed in English, with international circulation, and containing at least one geomorphology paper per year (Table 1). The journals are ranked according to the "impact factor" calculated by the *Science Citation Index* and *Social Science Citation Index* for 1986. Note that the data do not distinguish between American and foreign-based geomorphologists.

The journals most heavily used by geographical geomorphologists are not among those with the highest impact factors, which limits the visibility of research. Unchanged from the earlier survey by Costa and Graf (1984), the *Professional Geographer* continued to publish a disproportionately low number of geomorphology papers, while the *Annals* published a disproportionately high number when compared to the percentage of AAG members who specialize in geomorphology. Geographers (American and foreign-based) accounted for 51.2% of the geomorphology publications sampled, a figure that is magnified when compared to their percentage of the practicing geomorphologists. American geographers contribute relatively few articles to the international journals, relying more heavily on those published in the U.S.

Table 1
Published geomorphology papers, 1976–86

Journal	Impact Factor[a]	By Geographer	By Geologist	Others	Sub-total	All Papers	% Geomorphology
Geology	2.182	17	73	18	108	1499	7.2
GSA Bulletin	2.163	51	150	26	227	1591	14.3
American J. Science	1.859	9	5	5	19	485	3.9
Journal of Geology	1.827	16	29	9	54	545	9.9
Quaternary Research	1.750	8	28	16	52	457	11.4
Annals AAG	1.397	29	6	1	36	341	10.6
Water Resour. Research	1.389	32	19	75	126	1826	6.9
Geogr. Annaler (A)	1.000	165	19	33	217	236	91.9
Arctic & Alpine Resear.	0.987	55	25	33	113	397	28.5
Earth Surf. Form & Pro.	0.817	215	53	96	364	387	94.1
Zeit. Geomorphologie	0.730	165	66	75	306	341	89.7
Prof. Geographer	0.678	13	0	0	13	399	3.2
Prog. in Phys. Geogr.[b]	0.661	130	7	21	158	275	57.5
Journal of Hydrology	0.586	44	6	35	85	1461	5.8
Env. Geol. & Water Sci.	0.432	4	23	26	53	209	25.4
Catena	0.193	79	7	22	108	222	48.6
Physical Geography[c]	0.097	38	12	0	50	120	41.6
TOTALS	(Mean = 1.103)	1070	528	491	2089	10,791	19.4

Source: Data for 1976-80 period from Costa and Graf (1984).
[a]Impact factor = number of citations from journal in 1984–85 divided by total number of citable items in that journal in 1984–85, from the *Science Citation Index* and *Social Science Citation Index* for 1986.
[b]Started publication in 1977.
[c]Started publication in 1980.

The topical areas of research by American geographers in geomorphology were investigated by examining *Geographical Abstracts* (formerly *Geo Abstracts*), *Part A: Landforms and the Quaternary, Part B: Climatology and Hydrology* (Hydrology sections only), and *Part E: Sedimentology*. This bibliographic service provides a compilation of abstracts from formal publications having international coverage. Abstracts are classified by major subtopics in geomorphology.

The names of 262 American geographers in geomorphology were checked for entries in *Parts A, B,* and *E* of *Geographical Abstracts* for the years 1980–87. Of the 262 names, only 147 were referenced at least once in the eight years. Many of the others are recent Ph.D.s in geography, or among those that list geomorphology as a specialty but are not members of the AAG Geomorphology Specialty Group. A total of 22,139 abstracts were compiled in *Geographical Abstracts, Part A* over this time period, and American geographers account for 322 entries (1.45%). An additional 347 abstracts by American geographers in geomorphology were cited in the hydrology and sedimentology parts. Twenty-two researchers account for 50% of the papers published by American geographers.

The classification of entries provides an indication of where American geographers are making contributions to the field, in the sense of quantity of published research (Figure 1). Quaternary studies that emphasize physical environments, slope studies, and fluvial studies account for the greatest concentration of effort. Receiving slightly less emphasis have been publications on periglacial form and process; runoff and hydraulics; beaches, barrier islands, and other coasts; glacial landforms and sediments; weathering and related pedogenesis; soils; and regional physiography.

Topics most closely associated with sedimentology have received some attention by American geographers. The published research in karst has been dominated by a few researchers, notably M. J. Day (e.g., 1983, 1985). A relatively small effort has been forthcoming in research involving neotectonics and structural control, deltas, estuaries, tidal flats, glaciology, and geomorphological mapping. The low number of entries for applied geomorphology is an artifact of the classification scheme used by the editors of *Geographical Abstracts*.

Research by American geographers on volcanic form and process has been rather sparse, in spite of the opportunities afforded by the 1980 eruption of Mount St. Helens. Rosenfeld (1980) and Rosenfeld and Cooke (1982) outlined the preeruption sequence of events, the events of 18 May (directional blast, landslides and debris flows, pyroclastic activity, formation of the lava dome), and posteruption landscape development. Yamaguchi (1984) used tree coring to date previous eruptions of Mount St. Helens at A.D. 1800 and A.D. 1480 that produced distinct tephra layers. Mount St. Helens was the site of the 1986 Conference of the American Geomorphological Field Group, generating a renewed interest in the recovery of landscapes disturbed by catastrophism.

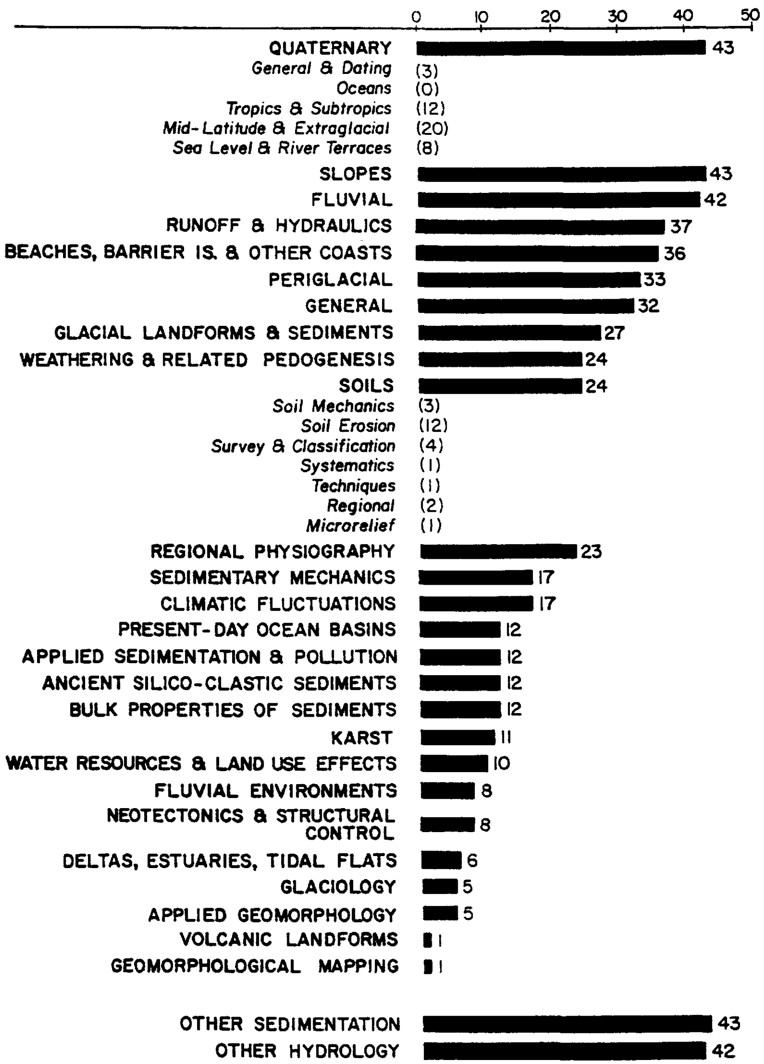

Figure 1
Number of abstracts authored by American geographers from 1980–87 in *Geographical Abstracts, Part A: Landforms and the Quaternary, Part B: Climatology and Hydrology,* and *Part E: Sedimentology*

A most-welcome addition to the literature on periglacial environments is the recent book edited by Giardino, Shroder, and Vitek (1987), *Rock Glaciers*. It is the most comprehensive work to date on the topic, with chapters by American geographers on a review of the knowledge base (Vitek and Giardino 1987b), rock glaciers as part of the alpine sediment cascade (Olyphant 1987), stratigraphy (Morris 1987), site characteristics and rock-glacier morphometry (Parson 1987), techniques of analysis (Shroder and Giardino 1987), movement dynamics (Shroder 1987), and geological engineering aspects of rock glaciers (Giardino and Vick 1987). The book also contains an extensive bibliography (Vitek and Giardino 1987a) that adds to its value as a guide to future research on what may be the largest landform of unconsolidated debris in alpine environment.

IMPORTANT CONTRIBUTIONS BY AMERICAN GEOGRAPHERS IN GEOMORPHOLOGY

It is possible to identify several areas where American geographers have had a significant impact on current thinking in geomorphology. These areas include the refinement and verification of geomorphic paradigms; the link among measurement, theory, and application in geomorphology (borrowing the theme of an IGU commission); separating the natural variation in geomorphic systems from the fluctuations triggered by human activities; and landscape ecology. It is also important to give credit to American geographers who have made important contributions to the development of techniques in geomorphology, regional geomorphology, and advances in Quaternary studies. These areas are addressed below.

Refinement and Verification of Paradigms in Geomorphology

Four paradigms affect the way in which geomorphologists in North America view landscapes (after Schumm 1977):

1. *Uniformity*—the laws of physics and chemistry control the operation of geomorphic processes today as they always have in the past.
2. *Landform Evolution*—landforms result from the interplay of the resisting framework, driving forces, and time.
3. *Complexity*—the interpretation of present-day landforms is complicated by changes in the resisting framework and driving forces over time, causing similar landforms to develop from different initial conditions, and landforms to respond to a change in the resisting framework and/or driving forces in opposite ways at different times.
4. *Thresholds*—abrupt changes may occur during landscape development, as geomorphic thresholds are exceeded; thresholds are values involving processes and/or forms that, when exceeded, initiate an episode of accelerated landscape change.

The paradigm of uniformity was developed in other branches of physical geology. It was extended to geomorphology by Strahler (1952, 1980), who is widely acknowledged as the father of modern quantitative geomorphology for his works on the dynamic basis of geomorphology and the logical extension of systems theory to the field. Dury (1980) underlined the need for catastrophism as part of uniformity.

With regard to landform evolution, great advances in understanding the sediment cascade for various geomorphic systems have followed from particularly innovative or rigorous research strategies. Notable work has been done by Trimble (1981) and Trimble and Lund (1982) in humid-region fluvial systems; by Graf (1987b) in a dryland river system; by Caine (1984) in alpine sectors in the Colorado Rocky Mountains; by Weirich (1985, 1986b) in high-energy glacial lakes; and by Nordstrom, McCluskey, and Rosen (1986), Allen (1988), and Sherman (1988) in sandy beach environments. These studies serve to illustrate several points. First, improved instrumentation must remain a priority among geomorphologists as part of the greater need to improve empirical coefficients and to test theories of sediment transport. Second, systematic data collection over a longer time period will yield more-meaningful results in geomorphic systems, where feedbacks and response times play an important role. Third, repeat photography and historical records of reservoir sedimentation offer attractive tools for drainage basin scale studies of the sediment cascade.

The complex response in geomorphology was expertly illustrated by Cooke and Reeves (1976), who proposed a model for arroyo development in the American Southwest. They demonstrated that arroyos in coastal California and southern Arizona are similar in form, but were generated by contrasting scenarios of environmental change. Complexity becomes the paramount consideration in Quaternary studies, as described below.

The thresholds concept was developed in the 1970s, and was quickly used to support episodic models of landscape development (e.g., dynamic metastable equilibrium). But recent work by American geographers has complicated this link. Coates and Vitek (1980a) presented an excellent summary of the development of the thresholds concept, with examples to illustrate the various types, and their social relevance. Salisbury (1980) found that thresholds must be used to explain why the merging of two streams does not always produce a predictable change in valley form.

However, reliance on thresholds to explain episodic landscape change has been tempered by Howard (1982), Graf (1983), and Rhoads (1988). They pointed out that significant landscape change can occur without transgressing thresholds, as disequilibrium is translated spatially throughout the fluvial system. Moreover, Costa and Cleaves (1984) showed that equilibrium and episodic landforms can be found in the same modern landscape.

The Link Among Measurement, Theory, and Application

Fluvial geomorphology continues to be the focus of much effort by American geographers. It is a subfield where American geographers have attained a high degree of success in achieving the synthesis, integration, and prediction aspects of the science. For example, the AAG Resource Publication by Graf (1985a) linked measurement and theory regarding biogeochemical processes in the Colorado River Basin with application to river-basin management issues.

The book by Mueller (1975) explored problems in political geography along the U.S.–Mexico border caused by geomorphic instability of the Rio Grande. He demonstrated that misunderstanding of the processes of channel change in an arid-region river led to long-standing problems of border demarcation. Toy and Hadley (1987) demonstrated the linkages among geomorphic principles, environmental impacts caused by human activities, and the effectiveness of reclamation practices.

General reviews of opportunities in applied physical geography and applied geomorphology were presented by Marcus (1979b) and Costa and Fleisher (1984), respectively.

Coastal geomorphologists have added to the success in linking measurement, theory, and application. Terich and colleagues (Komar, Lizarrage-Arciniega, and Terich 1976) used measurements of beach accretion and erosion in a computer simulation model to demonstrate that jetties can cause considerable shoreline change, even in areas of zero net littoral transport. Their findings have been used to guide development along sandy beaches of the Oregon coast.

Separating Natural and Human-Triggered Variation in Geomorphic Systems

The most difficult problem facing geomorphologists may be separating the natural variation in geomorphic systems from fluctuations triggered by human activities. The techniques that are used to make the distinction must be sufficiently refined to detect change over multiple spatial and temporal scales. Graf (1979) combined photogrammetric measurements from historical photographs with field measurements to judge the impact of gold and silver mining on mountain stream systems in Colorado. Threshold values of erosive force were surpassed in response to changes in general basin vegetation cover, valley-floor vegetation, channel slope, width, and roughness, all subject to human impact.

A study by Marston and Lloyd (1985) utilized the water-budget approach to explain changes in water supply, and to isolate the effects of channel modifications along the Rio Grande below El Paso, Texas.

The effect of silvicultural activities on channel equilibrium and sediment storage in forest streams can be assessed using the methods described by Marston (1982). Sternberg (1987) attempted to separate the influence of deforestation on flooding and channel changes in the Amazon River from the influence of rainfall variations and neotectonics.

The differential effect of military maneuvers on aeolian transport was the subject of a paper by Marston (1986b). Walker and Mossa (1986) used 10 case studies along the shoreline of Japan to contrast the influence of human modifications with that of tectonic processes, tsunamis, and storm surges.

Overall, however, the human-environment (synthesis) theme is not as common in the published work of American geographers in geomorphology as one might expect, given the training of geographers. A survey of consulting activity would probably reveal the true extent of this type of work.

Landscape Ecology and Earth-System Science

The application of concepts and techniques from geomorphology to ecosystem studies and terrain analysis represents a great opportunity for the discipline, given the current need for an interdisciplinary approach to complex environmental problems.

Several examples are available of such research, conducted by American geographers in geomorphology.

Caine and his coworkers (Swanson et al. 1988) claimed that ecosystem behavior can be predicted by a better understanding of how landforms affect those processes. They noted that landform-ecosystem interactions may take multiple forms, and that patterns imposed by one set of interactions may be overridden by another set. The link between landform stability and ecosystem development remains to be quantified. Marston (1989, in press) has traced research on the link between sediment transport and nutrient export from agricultural and forested ecosystems. No consistent proportion of nitrogen or phosphorus is released by either sediment loss or dissolution, undermining the usefulness of any nonpoint-source models that rely on this assumption.

Stream ecologists have suddenly realized that fluvial geomorphologists can provide insights regarding physical habitat features. Working in an interdisciplinary group, Dixon and his coworkers (Brussock, Brown, and Dixon 1985) proposed a regional classification of stream habitat. It is based on channel form and regular changes along the longitudinal profile in physical features that comprise rearing habitat (e.g., pool-riffle ratios) and spawning habitat (e.g., gravel bars).

The extent to which geomorphologists take advantage of this opportunity will depend on their initiative and skill in working with other physical geographers and researchers in engineering and the other natural sciences.

The National Aeronautics and Space Administration (NASA) convened an Earth System Sciences Committee (1986). It has recommended a coordinated sequence of specialized space-research missions for studies of Earth-system processes, and an interdisciplinary program of basic Earth-system research in conjunction with other federal agencies. According to the report, among the many areas to which geographical geomorphologists can make a contribution are studies of sedimentary processes and biogeochemical cycles. Other opportunities exist for the pursuit of Earth-system science through the International Geosphere-Biosphere Program (IGBP) of the International Council of Scientific Unions and the Annual Workshop in Earth System Science held at Pennsylvania State University.

A volume is being prepared jointly by the Institute of Geography at the USSR Academy of Sciences and U.S. geographers, summarizing what is known about the geography of change in global-resource systems and major scientific questions within the goals of IGBP to which geographers may contribute. Some interest has also been expressed for the formation of an "Earth Systems" Specialty Group within the AAG (Borchert 1987). The potential exists for major contributions to these efforts by geomorphologists, by extending their interest in "mega-scale" geomorphology.

Geomorphic Techniques

Geomorphologists have developed a wide range of techniques for data collection and analysis, including field, laboratory, and numerical techniques (Table 2). Many of these have been adopted from cognate fields, but all have been used by American geographers in geomorphology. A sampling follows.

Several advances in field instrumentation by American geographers in geomorphology have been notable. Leatherman (1978) has devised a low-cost and effective

Table 2
Geomorphic techniques used by geographers

	Field Techniques	
Air reconnaissance	Chemical tracers	Sand/pebble tracers
Augering	Isotope tracers	Water tracing
Automatic weather stations	Particulate tracers	Mass-balance studies
Dune sand movement	Particle/stone shape	Petrology
Field mapping	Resistivity measurements	Rock jointing
Soil/rock creep measurement	Seabed drifters	Runoff plots
Frost heave	Suspended sediment sampling	Soil moisture/tension/pressure
Leveling/surveying	Bedload measurement	Throughflow measurement
Dendrochronology	Solute sampling; conductivity	Infiltration measurement
Lichenometry	Gravel/pebble size	Aqualung diving
Discharge measurement	Seismic survey	Photoelastic-stress analysis
Macrofossils	Sounding (lake/sea)	Peat boring
Macrofabric of tills	Stone counts	Timelapse photography
Dye tracers	Stone orientation	
	Laboratory Techniques	
Air-photo interpretation	Heavy-mineral analysis	Soil thin sections
Landsat interpretation	Isotope techniques	Microfossils
Radar-imagery analysis	Hardware simulation	Wave-tank models
Carbon-14 dating	Morphometry	X-ray powder photography
Chemical analysis: sediments	Pollen analysis	X-ray diffraction
Chemical analysis: water	Particle size: sieve	X-ray fluorescence
Cold laboratory experiments	Particle size: silt/clay	Isotope analysis of water
Digitizer	Coulter counter	Spectrophotometry
DTA	Index properties (Atterberg)	Till microfabric
Electron microscopy	Direct shear box	Quantimet analysis
Experimental rock weathering	Triaxial tests	
Flume studies	Solution experiments	
	Numerical Techniques	
Experimental design	Spectral analysis	Directional statistics
Analysis of variance	Stochastic processes	Information-content statistics
Correlation structures	Trend surface analysis	Differential equations
Simple regression	Computer mapping	Mass/energy-balance equations
Multiple regression	Mathematical modeling	Thermodynamic models
Canonical correlation	Digital simulation	Mainframe computers
PCA/Factor analysis	Analogue modeling	Microcomputers
Serial correlation	Spatial analysis	

Source: British Geomorphological Research Group International Research Register.

sand trap for coastal studies (Nordstrom, McCluskey, and Rosen 1986) and desert dune studies (Marston 1986b). Toy (1983) developed an instrument for measuring small-scale changes in elevation, as might be required in studies of aeolian erosion-deposition or frost heave. Graf (1985b) outlined methods for making geomorphic measurements from ground-based photographs, a technique he utilized effectively in other published research (Graf 1978, 1979). Mandel, Sorenson, and Jackson (1985) described the use of erosion pins to estimate erosion on drastically disturbed lands. Day (1984) compared rates of erosion for various carbonate rocks from a wide range of locations through the use of "erosion weight-loss tablets." Weirich (1984, 1986a) designed a network of optical and thermal sensors to document the internal characteristics of turbidity and density currents in lakes.

Field techniques need greater utilization in two respects. First, a strong need exists for initiating and maintaining long-term field monitoring of geomorphic systems, in the tradition of experimental watershed studies that flourished in the 1960s. The data set compiled by Caine (1984) over two decades has been invaluable in this regard. The annual cycle common to many funding programs has been a deterrent to long-term research. Reoccupying old study sites is an alternate strategy in some cases, if a mechanism exists to recover former field stations. The ongoing work by Marston (1986b) in desert dunes and by Weirich (1987) with fire-related debris flows are examples.

Second, greater use should be made of controlled field-scale experiments. Laboratory studies traditionally yield results that alone have limited applicability at the landscape scale. Field studies, without a control on process rates, often frustrate researchers who wait for the "characteristic" event to occur. Results with rainfall simulators (e.g., Luk, Abrahams, and Parsons 1986; Abrahams, Parsons and Luk 1988; Dolan and Marston 1989) and with portable wind tunnels are particularly encouraging.

The most-recognized contribution by American geographers to the advancement of dating techniques is certainly the body of published literature by Dorn and Oberlander; their 1982 paper was cited for the GSA Kirk Bryan Award. They have been responsible for some remarkable developments in the use of rock varnish as an absolute dating tool and as a record of environmental change (climatic and tectonic). Dorn and Oberlander were the first to identify rock-varnish bacteria in the laboratory. They have developed two new rock-varnish dating techniques, radiocarbon dating of organics extracted from rock varnish, and cation-ratio dating. They also have utilized stable carbon isotopes, micromorphology of dust layers in rock varnish, and microchemical laminations in rock-varnish layers as indicators of fluctuations in climate.

Most recently, Dorn (1988) has used rock varnish on Quaternary alluvial fans in Death Valley to reveal three cycles of fan development controlled by climatic change and tectonic activity. Dorn received the 1988 G. K. Gilbert Award for this latest effort. Geomorphologists worldwide are looking to Dorn and his colleagues for further developments in environmental reconstruction using rock varnish.

Several other studies can be cited to illustrate the range of applications in geomorphology using dating techniques. Dendrogeomorphology has been used as a tool in the analysis of flooding, mass movement, and rock glaciers (Butler 1979; Shroder and Giardino 1987). Marcus and Marcus (1980) demonstrated the usefulness of stratigraphic and radiocarbon data from a drained tarn in the reconstruction of Holocene climates. Butler, Sorenson, and Dort (1983) combined geomorphic, stratigraphic, palynologic, and pedologic evidence to discriminate among various types and ages of morainic deposits.

Three-dimensional fabric analysis has been applied to a wide range of sedimentary environments by American geographers in geomorphology. For example, it has been applied to sorted stone stripes (Nelson 1982), solifluction lobes (Nelson 1985), hillslope colluvium (Mills 1983), debris flows from Mount St. Helens (Mills 1984), glacial till (Mark 1974), and rock glaciers (Giardino and Vitek 1985). Eigenvector analysis of fabric data holds promise as a means of differentiating various types of cobble-boulder-size deposits when the origin is uncertain.

A very thorough study by Dixon, Thorn, and Darmody (1984) of chemical weathering on a nunatak of the Juneau Icefield pointed out the importance of dissolution and clay-mineral transformation in periglacial environments. A convenient chronosequence was provided by collecting soil data on successively lower berm levels, which were carved into the nunatak during progressive downwasting of the adjacent Taku Glacier. Dixon and his coworkers utilized a variety of laboratory techniques to analyze chemical alteration of nunatak gruss and soils, including atomic-absorption spectrophotometry (AA), X-ray diffractometry, and scanning electron microscopy (SEM). Changes in the molar ratios of mobile-to-resistant oxides were used to detect contrasting degrees of weathering. The work also highlighted the possible significance of aeolian inputs of fines to account for textural and mineralogical anomalies observed in the near-surface soil profile.

Laity (1983) also used SEM interpretations to judge the importance of diagenetic controls on groundwater sapping and valley formation in the Colorado Plateau region.

Morphometric analyses of drainage basins received considerable attention in the early 1980s. Factors controlling the direction, density and pattern of channel networks have been the subject of benchmark papers by Abrahams (e.g., 1980a, 1980b, 1983, 1984b) and Abrahams and Ponczynski (1984). This coherent body of work was recognized by the AAG Geomorphology Specialty Group when they presented the G. K. Gilbert Award to Abrahams in 1985. However, early enthusiasm for the use of drainage-basin morphometric variables to estimate water and sediment production has been tempered by the realization that the present-day hillslope and channel network morphology may include relict components which do not contribute to modern water and sediment cascades.

Remote-sensing techniques for geomorphologists have been outlined by Rosenfeld (1984) and are common tools employed by geographers. Expectations remain high for new applications in geomorphology as new sensors with improved technology are launched. In particular, the remote-sensing platforms now being designed by NASA for the Earth Orbiting Space Station of the 1990s will afford opportunities for study of mega-scale geomorphology, including catastrophic geomorphic events and tectonic geomorphology. However, the traditional reliance on expensive and time-consuming field research will not be replaced (Graf et al. 1980).

Geographers have been somewhat reluctant to utilize numerical techniques, given their strong tradition of field work. But some researchers have recognized the benefits of both. Computer-aided mapping has been utilized more and more for simulation work (e.g., Band 1985) and erosion mapping (e.g., Marston 1986a; Dolan and

Marston 1989). A recent book by Kirkby et al. (1987) reviewed computer simulation in physical geography, including the important contributions by American geographers. Cluster analysis has been applied to pollen counts to establish the spatial extent of distinct pollen assemblages (Elliott-Fisk et al. 1983).

Trend-surface analysis has been applied to a wide range of geomorphic environments. For instance, trend-surface mapping of buried organic horizons shows promise as a tool for recognizing paleosurfaces and separating drift sheets in areas with limited subsurface data (Rhoads, Rieck, and Winters 1984). Meierding (1982) used the technique to reconstruct the equilibrium-line altitudes of Pleistocene glaciers, and Jones and Cameron (1977) analyzed shifts in particle-size characteristics of barrier-island sands. The ready availability of microcomputers to researchers with the software discussed above will contribute to greater use of numerical modeling in the future.

Development of Theory in Geomorphology

Geomorphology has been described as a "derivative science, borrowing techniques and generalizations from other sciences" (Graf et al. 1980). The belief exists among some geomorphologists that theoretical work is tangential to the mainstream of geomorphology. However, a book by Thorn (1988) should help dispel these notions. This introductory text makes the convincing argument that field work is made more valuable when guided and based upon an established theoretical foundation. Elsewhere, Thorn has outlined advances in the development of theory with regard to ergodic reasoning, time and space in geomorphology (see Thorn 1982), and landscape evolution.

Geomorphic models have been described as theories or hypotheses about system form, and/or process, and/or behavior (Woldenberg 1985). By this definition, much of the effort in geomorphology could be considered as modeling. However, a relatively small effort to date has been put forward by geographers seeking a theoretical basis for form and process in geomorphic systems. Studies of channel networks by faculty at SUNY–Buffalo and their colleagues are significant exceptions to this trend. For instance, optimality in network branching phenomena in nature has been addressed by drawing analogies between fluvial systems and biological systems (Roy and Woldenberg 1982; Woldenberg and Horsfield 1983, 1986). Woldenberg (1969, 1979) has also added to our understanding of spatial hierarchies in geomorphology, again with ties to biological systems.

However, it appears that greater explanation of channel-network development at the landscape scale is being achieved by presuming the operation of stochastic processes than by seeking the deterministic explanation from exact physical-chemical laws (see, e.g., Abrahams 1984a; Abrahams and Mark 1986). Deterministic models will continue to work best for small-scale studies, but empiricism without prediction is still favored by too many geomorphologists when their deterministic-modeling efforts meet with frustration.

The application of fractal concepts to geomorphic systems has been reviewed by Goodchild and Mark (1987). Fractal surfaces are comprised of values that are dependent on neighboring values at all scales. Fractal geometry deserves more attention from geomorphologists as a tool for analyzing various topics—thresholds of erosion by overland flow, scales of roughness in hillslope morphology, and numerous others.

Fractals have already been used with some success in describing coastlines and river courses. Software is becoming more readily available for research and teaching purposes (e.g., Kirkby et al. 1987).

The Spatial Theme in Geographical Geomorphology

Baker (1986) has noted that regional studies of geomorphology were a major focus of geographers until the middle of this century. Comprehensive works on regional geomorphology have been sparse in the geomorphic literature in North America during recent years, until the appearance of the GSA Centennial Special Volume edited by Graf (1987a). Nine of the 13 chapters were authored or coauthored by American geographers. This excellent compendium avoided descriptive geomorphology in favor of an emphasis on modern process and form, with some reference to earlier time frames, including the Quaternary. The volume represents an assessment of geomorphologic theory and a review of selected geomorphic research problems, organized by physiographic province. It represents a modern approach to regional synthesis in geomorphology, departing from the more descriptive "physiography" of the first half of this century.

Mountain regions have received considerable attention from American geographers in geomorphology, and this attention is deserved. Mountain regions are the setting for polygenetic landforms and extremes in rates of geomorphic processes. Applied geomorphologists are noting that mountain regions are being subjected to population pressures in many regions of the world: for recreational development and silviculture in the developed world, and for subsistence farming in the developing world. The text by Price (1981), *Mountains and Man,* provides a particularly useful synthesis of environmental perception, geomorphology, soils, biogeography, land use, and human-environment relationships.

Barsch and Caine (1984) presented a journal-length synopsis of mountain geomorphology, focusing on the high frequency of catastrophic events and the high potential for accelerated erosion where mountain terrain is impacted by human activity. Caine (1983) also authored a book that epitomizes the "new" process-geomorphology approach to regional studies, summarizing 20 years of work in the mountains of northeastern Tasmania.

A special issue of the journal *Mountain Research and Development* (Ives and Ives 1987) was devoted to an analysis of the "Theory of Himalayan Environmental Degradation" which has caused so much alarm and interregional conflict. This excellent work explored whether current mountain land-use practices produce the downstream destruction accredited to them, and if so, what mitigation measures can be pursued. The papers in this volume succeed in exposing the problems that result when wide-ranging hypotheses are presented as fact, with little geomorphic field data to support them.

Quaternary Studies

Reconstructing Quaternary environments has been a major focus of interest by American geographers in geomorphology (Figure 1). To construct a reliable hypothesis for past environmental change, the most successful researchers rely on a wide range of correlative evidence. Work by Holliday (1985a, 1985b) at the Lubbock Lake site in Texas has significance because the sequence at that site is one of the most tightly integrated records of late Quaternary human occupance, sedimentation, and soil formation to be documented in North America. Elsewhere in the southern Great Plains, Hall and Lintz (1984) used a sequence of radiocarbon-dated buried trees, buried soils, a carbonate zone, and molluscan fauna to reconstruct climatic variations.

Butzer's (1981) work in Spain deserves attention because of the varied evidence he utilizes to reconstruct a complex sequence of environmental phases: external-sediment flux in karst cave columns, cave slope and roof rubble, chemical precipitates, cryoturbations, fine soil derivatives, and cultural components.

Several studies illustrate the complex nature of the environmental change that Quaternary scientists are trying to detect and measure. In a study of toposequences of soils under a subalpine forest, Reider (1983) found that the soils are in a state of disequilibrium with the current environment because of oscillating ecotones during the Pleistocene and Holocene. Knox, McDowell, and Johnson (1981) reconstructed the magnitude and causes of floods over the last 10,000 years for the Driftless Area of Wisconsin, an area where controversy remains regarding the effects of continental glaciation. Working in the same area, McDowell (1983) demonstrated the episodic nature of stream response to changes in climate and vegetation during the Holocene.

Miller (1985) has utilized 40 years of data from the Juneau Icefield to reconstruct paleoenvironments in southeast Alaska during late Neoglacial times. The study was exceptional in the way it used multidisciplinary data sets to eventually explain glacier response to the complex interactions of astronomical, geophysical, atmospheric, oceanic, and anthropogenic factors.

PROFESSIONAL AFFILIATIONS FOR AMERICAN GEOMORPHOLOGISTS

The principal professional organizations for American geographers in geomorphology are the Geomorphology Specialty Group of the AAG, the Quaternary Geology and Geomorphology Division of the GSA, the American Quaternary Association, and the Soil Science Society of America. The American Geomorphological Field Group and Friends of the Pleistocene hold field-oriented meetings.

Ample opportunities for interaction with foreign colleagues across the subfields of geomorphology is provided by the Annual Binghamton Geomorphology Symposia, the British Geomorphological Field Group, the Guelph Symposia on Geomorphology, the International Conferences on Geomorphology, the International Quaternary Association, the International Geographical Union, the International Symposium on Erosion and Sedimentation in the Pacific Rim, and the International Union of Geological Sciences. In addition, a great number—too numerous to list—of one-time topical symposia that are of interest to geomorphologists are offered each year.

The AAG Geomorphology Specialty Group

The Geomorphology Specialty Group of the AAG provides a forum for 268 members (May 1987 data), ranking ninth in size among the 38 specialty groups in the association. Geomorphologists present a large number of papers at the annual meetings of the AAG (Table 3), approximately 90% of which are by American geographers. The specialty group also sponsors six or more special sessions each year. Each year since 1983, the AAG Geomorphology Specialty Group has presented the G. K. Gilbert Award for Excellence in Geomorphic Research to the author(s) of a significant recent contribution to the published literature in the field of geomorphology (Table 4).

The Geomorphology Specialty Group was formed through the efforts of J. D. Vitek and C. E. Thorn in the late 1970s, when geomorphologists perceived that they were not being included in AAG activities in proportion to their number within the association (Costa and Graf 1984). This problem is beginning to be addressed by the AAG through an increase in the number of physical geographers nominated for AAG offices and awards. For instance, the Warren J. Nystrom Award for a paper based on dissertation research in geography by a recent Ph.D. recipient has been awarded by the AAG to five American geographers in geomorphology: R. S. Hayden in 1980, R. A. Marston in 1981, F. H. Weirich in 1984, K. K. Hirschboeck in 1987, and D. W. May in 1988.

The GSA Quaternary Geology and Geomorphology Division

The Quaternary Geology and Geomorphology Division of the GSA provides a forum for 1,435 members (October 1987), ranking third in size among the 10 divisions of the GSA. A large number of geomorphology papers are presented at the annual meetings (Table 3), approximately 10% by American geographers.

Table 3
Geomorphology papers presented at AAG and GSA meetings

Year	AAG	GSA	Year	AAG	GSA	Year	AAG	GSA
1976	16	44	1980	61	77	1984	86	81
1977	56	30	1981	71	72	1985	60	95
1978	76	49	1982	74	66	1986	72	89
1979	62	62	1983	70	47	1987	86	124
						Mean	65.8	69.7

Source: Data for the period 1976–80 from Costa and Graf (1984).

Table 4
Recipients of the G. K. Gilbert Award, presented by the AAG Geomorphology Specialty Group

Year	Recipient	Contribution to Geomorphology
1983	J. Ross Mackay	Permafrost studies in the Mackenzie River delta area
1984	Will Graf[a]	Fluvial processes in the southwest United States
1985	Athol Abrahams[a]	Channel networks
1986	Karl Butzer[a]	Archaeology as human ecology
1987	Derek Ford	Karst geomorphology and Quaternary chronologies in the Castleguard Cave area of the Canadian Rockies
1988	Ron Dorn[a]	The use of rock varnish to distinguish three episodes of alluvial fan development in Death Valley

[a]American geographers

The division presents several prestigious awards, with an occasional American geographer as a recipient. The Distinguished Career Award was first presented in 1986. The Kirk Bryan Award is presented for an outstanding paper in Quaternary geology and geomorphology; the 1986 award was presented to R. I. Dorn and T. M. Oberlander for their 1982 paper, "Rock Varnish."

The Gladys W. Cole Memorial Research Award is used to support the investigation of the geomorphology of semiarid and arid terrains in the U.S. and Mexico. It was awarded to W. L. Graf in 1984 to support his study of radionuclides in dryland rivers, and to A. D. Abrahams in 1985 for use in his studies of rock-slope form in the Mojave Desert (see Abrahams and Parsons 1987).

The Robert K. Fahnestock Award is presented to the applicant having the best proposal in sediment transport or related aspects of fluvial geomorphology. It was awarded to R. Andrle in 1987 for his study of pools and riffles in low-sinuosity alluvial streams.

The division also awards two Mackin Grants each year for support of graduate-student research in Quaternary geology and geomorphology, one award to a master's student and one to a doctoral student. Mark Gonzalez (University of Wisconsin–Madison) and Dorothy Sack (University of Utah) are two geography students in American universities who have been selected for Mackin Grants in recent years.

The Binghamton Symposia in Geomorphology

The First Geomorphology Symposia in 1970 was organized and hosted by Donald R. Coates and Marie Morisawa at SUNY–Binghamton. After a long tenure on that campus, the annual event has been moved to other locales, but the name "Binghamton Symposia in Geomorphology" has become associated with this distinguished international, interdisciplinary meeting. American geographers have contributed 9.5% of the papers delivered and later published by the symposia (Table 5). Four of the 18 volumes have utilized American geographers as editors: *Thresholds in Geomorphology* by Coates and Vitek (1980b), *Space and Time in Geomorphology* by Thorn (1982), *Models in Geomorphology* by Woldenberg (1985), and *Hillslope Processes* by Abrahams (1986).

International Geomorphology Activities

The International Geographical Union holds a congress every four years. Immediately before the main congress, and in years between the main congresses, IGU commissions, working groups, and study groups meet at separate venues to examine past and ongoing research in the field and to hold more formal paper sessions. The commissions, working groups, and study groups operating as of 1988 that are of interest to geomorphologists are listed below, with the date they were established (Walker 1987):

Measurement, Theory, and Application in Geomorphology (1968)
Mountain Geoecology (1976)
Coastal Environment (1952)
The Significance of Periglacial Phenomena (1949)
International Hydrological Programme (1964)
Geomorphology of River and Coastal Plains (1980)
Morphotectonics (1980)
Geomorphological Survey and Mapping (1968)
Man's Impact on Karst Areas (1984)

Table 5
The Binghamton Symposia in geomorphology

No.	Year Held	Topic	Editor(s)	Contributors: Amer; Can Geographers	Total
1	1970	Environmental Geomorphology	D. R. Coates	2	18
2	1971	Quantitative Geomorphology	M. Morisawa	2	12
3	1972	Coastal Geomorphology	D. R. Coates	2	16
4	1973	Fluvial Geomorphology	M. Morisawa	1	20
5	1974	Glacial Geomorphology	D. R. Coates	0	16
6	1975	Theories of Landform Development	W. N. Melhorn and R. C. Flemal	2	16
7	1976	Geomorphology & Engineering	D. R. Coates	0	20
8	1977	Geomorphology in Arid Regions	D. O. Doehring	1	19
9	1978	Thresholds in Geomorphology	D. R. Coates and J. D. Vitek[a]	2	29
10	1979	Adjustments of the Fluvial System	D. D. Rhodes and E. J. Williams	2	25
11	1980	Applied Geomorphology	R. J. Craig and J. L. Craft	1	33
12	1981	Space & Time in Geomorphology	C. E. Thorn[a]	4	20
13	1982	Groundwater as a Geomorphic Agent	R. G. LaFleur	1	19
14	1983	Models in Geomorphology	M. J. Woldenberg[a]	1	31
15	1984	Tectonic Geomorphology	M. Morisawa and J. T. Hack	3	22
16	1985	Hillslope Processes	A. D. Abrahams[a]	2	28
17	1986	Aeolian Geomorphology	W. G. Nickling	8	27
18	1987	Catastrophic Flooding	L. Mayer and D. Nash	4	27

[a]American geographers

At the 1988 IGC in Sydney, 12 of the 112 geomorphology papers/posters presented were authored by American geographers.

Much excitement has been generated over the prospect of an international organization for geomorphologists. In September 1985, the British Geomorphological Research Group hosted the First International Conference on Geomorphology in Manchester, England. It was attended by 675 geomorphologists from 51 countries. Most in attendance agreed that an international organization was desirable (Sugden 1987). A committee was formed to explore the ramifications of establishing an organization, and its findings will be reported at the Second Conference, to be held in West Germany in 1989.

Meanwhile, a Newsletter and World Directory of Geomorphologists are being developed. The Proceedings of the First Conference have been published by Wiley and Sons (Gardiner 1987) in two volumes, totaling 2590 pages. Abrahams (1987), Psuty and Allen (1987), Sherman (Sherman and Greenwood 1987), and Walker (1987) each published a paper on behalf of American geographers from a total of 78 presentations by American geomorphologists.

Walker and Orme (1986) have summarized the prominent themes of the meeting and arrived at two main conclusions: first, geomorphology remains a field-oriented discipline, although laboratory experiments and theory development are increasing in importance. Second, geomorphology is a global science, in the sense of interest worldwide, and participation by American geographers must be increased.

GEOMORPHOLOGY IN EDUCATION

The decline of both field geology and the number of geomorphologists associated with academic geology units has been noted by Costa and Graf (1984). At the same time, geomorphology has gained in strength within geography departments at the university level in the U.S. Vitek (1988) ascribes this shift to the dynamic growth in the petroleum industry, hydrogeology, sedimentology, and engineering geology, which has attracted geology students away from potential careers in geomorphology.

To explain the lack of support for geomorphology by other geology faculty, Ritter (1988) cited a "lack of unity" in the discipline caused by the dichotomy of purpose (historical versus process-oriented studies) and vagueness of paradigms. Actually, the dichotomy of purpose to which Ritter refers is part of the pluralism claimed as a strength of the discipline by others. Moreover, paradigms in geomorphology have been stated most succinctly by a geologist (Schumm 1977). His article is addressed to other geoscientists who may "cling to ideas which lend themselves to easy pedagogy but are possibly wrong and certainly do not reflect geomorphic science as it is today or what it will be like in the future."

Meanwhile, several generations of students in geography have emerged as research professors in geomorphology, thanks to a tradition of inspiration that began with their mentors during the "quantitative revolution" in geomorphology in the 1950s. Marcus (1979a) noted that "employment opportunities have been good [and] basic and applied research has thrived" for physical geographers. In terms of employment, 74% of American geographers in geomorphology are employed by universities, 11% are employed in the private sector (including self-employed), and 9% are employed by federal and state governmental agencies. Given this situation, it is somewhat surprising that, of the 191 U.S. universities that list department specialties in the 1987–88 *Guide to Departments of Geography in the United States and Canada*, only 72 list geomorphology and 33 list soils as department specialties.

A glaring omission by American geographers has been their failure to author new introductory texts in geomorphology. The most recent effort was by Butzer (1976), distinguished from other texts by weaving dynamic geomorphology into a regional framework. However, the themes in geomorphology toward which American geomorphologists are making significant contributions are not well represented in the texts that are receiving widest adoption—those authored by geologists. Similarly, American geographers contribute few articles on the teaching of geomorphology to the *Journal of Geography* and the *Journal of Geological Education*.

American geographers working in geomorphology today benefit from paradigms that provide a broad scientific foundation for the discipline. American geographers in geomorphology have never before had so many opportunities for presentation and publication of research. Geographers are publishing at a high rate compared to the overall number of geomorphologists, and they are making important contributions beyond the scope of geographic inquiry.

While gaining new perspectives from greater international collaboration and interaction with geomorphologists from other backgrounds, geographical geomorphologists need to leave an imprint on the study of landforms and soils that reflects their training as geographers. Geomorphology is undergoing a reorganization that may mask the identity of American geographers within geomorphology, but the need will remain for certain contributions that are best supplied by those possessing a background in geography. The synthesis, integration, and predictive spatial modeling that mark geomorphic research by geographers are imprints that should be emphasized at a time when pluralism exists in the discipline. Unfortunately, geographers are missing an opportunity to leave a distinct imprint on the study of landforms and soils by often pursuing research that duplicates the objectives of geologic inquiry.

The strongest contributions by American geographers to the discipline will be in studies that refine existing paradigms; link measurement, theory, and application; separate natural and human-triggered variation in geomorphic systems; and pursue landscape ecology and Earth-system science. Geographers will continue to contribute their fair share toward the development of research techniques in geomorphology and toward the differentiation of geomorphic systems in time and space (i.e., Quaternary studies and regional geomorphology).

More theoreticians are needed among the ranks of American geographers in geomorphology. Long-term field monitoring of geomorphic systems is desired to better understand adjustment of form and process over the scale of decades. And greater reliance on controlled field-scale experiments is urged, to achieve more meaningful results at a scale that can link laboratory and landscape scales of understanding in geomorphology.

New introductory texts in geomorphology, authored by American geographers, are desired to advance the themes of geographical geomorphology in education. Finally, American geographers in geomorphology must seek more interaction with their colleagues on an international level and publish more in the high-impact-factor journals to ensure their efforts receive the widest recognition.

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