S T U D I A G E O M O R P H O L O G I C A C A R P A T H O - B A L C A N I C A
vol. LIII–LIV, 2019–2020: 9–32 PL ISSN 0081-6434

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DISCONNECTIVITY IN GEOMORPHOLOGY

Abstract: "Buffers, barriers and blankets" have become recognized as increasingly important components of landscape that constrain rates of denudation. Nevertheless, connectivity continues to be emphasized in recent geomorphic discussions. It is surely the case that spatial and temporal disconnectivity is at least as common as connectivity in geomorphic sediment systems. The importance of intermittency of sediment movement events (disconnectivity over time) has been understood as fundamental in most understandings of landscape evolution. The development of new techniques that make the term connectivity more mathematically precise are much to be welcomed. But the case is argued that more progress has been made in understanding geomorphological spatial and temporal change by interrogating disconnectivity, discontinuities and thresholds.

Keywords*:* disconnectivity, sediment pathways, spatio-temporal scale, North American Cordillera, Karakorams

INTRODUCTION

"Buffers, barriers and blankets" have become recognized as increasingly important elements of geomorphic systems that constrain rates of denudation (Fryirs et al. 2007; Lu, Richards 2008; Lane et al. 2009). In a wide-ranging discussion of "discontinuities" R. Brunet (1968) argued that disconnectivities in space and over time are crucially important in all aspects of geography. Disconnectivity is generally marked by the presence of thresholds, identified as rapid changes of kind (spatial discontinuities) or of rhythm and sense of direction (temporal discontinuities). Spatial disconnectivity controls rates of erosion in widely varied landscapes (Brunsden 1993; Kirchner, Ferrier 2013; Willenbring et al. 2013; Slaymaker 2013); and temporal disconnectivity reflects the importance of intermittent sediment movement in landscape evolution (Schumm, Lichty 1965). Indeed, R. Brunet (1968) identified four kinds of thresholds that characterize temporal disconnectivity: (a) threshold events such as the point of erosion initiation; (b) changing thresholds such as those exhibited by the amount of sediment transported by a river which increases slowly with discharge, then increases suddenly and reaches a limit; (c) reversing thresholds, such as the inflexion point in Hjulström curves (Hjulström 1935); and (d) saturation thresholds, such as the limit of regolith infiltrability (Horton 1941). Publications focused on connectivity have become something of an industry recently (e.g. Wohl et al. 2018) and exploration of disconnectivity has been comparatively neglected. The claim that consideration of connectivity automatically includes consideration of disconnectivity as the opposite end of a spectrum seems inadequate justification for this neglect.

The following discussion asks the reader to consider the extent to which the "real world" is characterized by barriers to change (disconnectivity) (Brunsden 1993) and thresholds.

WAYS OF THINKING ABOUT DISCONNECTIVITY/CONNECTIVITY THROUGH PREFERRED WATER PATHWAY ANALYSIS

HYDROLOGICAL GEOMORPHOLOGY: THE HORTONIAN REVOLUTION

Geomorphology was forever changed by its close identification with hydrology, as defined by Robert Horton (Horton 1945; Dunne et al. 1975; Kennedy 1992). River basin morphometry and the water balance suggested the existence of a kind of equilibrium between geomorphic form and process that was guaranteed by the preferred pathways of water movement. Even karst geomorphology that had traditionally been dominated by exotic semantics was eventually persuaded of the centrality of hydrological processes (Ford, Williams 2007). Concepts like equilibrium, balanced sediment budgets and the coupling of hillslope and channel processes (e.g. Harvey 2002; Savi et al. 2013) leading to the recent emphasis on connectivity have come to dominate the journals (e.g. Wohl et al. 2018).

GENERAL SYSTEMS THINKING IN GEOMORPHOLOGY

Mass and energy fluxes through landscapes as influenced by connectivity and disconnectivity in space and thresholds over time are effectively considered under the conceptual framework of general systems theory (Chorley 1962). The "connectedness" literature in systems ecology (Odum 1994; Forman 1995) has much in common with the connectivity discussion in geomorphology; drivers of adaptive cycles in panarchies include connectedness, resilience and mass flux (Holling 2001). Disconnectivity is here defined as the degree to which a system resists the movement of water and sediment under the influence of external drivers and system structural and functional properties. The discussion of disconnectivity provides a counterbalance to the recent emphasis on connectivity and associated assumptions of connectedness in space and over time.

TIME, SPACE AND CAUSALITY

Discussion of spatio-temporal scale problems in geomorphology was introduced in a remarkable paper by S.A. Schumm and R.W. Lichty (1965). By demonstrating the changing status of variables in geomorphic systems over varying time and space scales they raised the fundamental question of the nature of connections, if any, between geomorphic systems at different scales. (Schumm 1977, 1994). S.N Lane and K.S. Richards (1998) revisited the S.A. Schumm and R.W. Lichty paper and demonstrated the irrelevance of short time scale and small space scale research to the understanding of longer term aspects of landform behavior. A shaft of light was cast on this topic by M Church (2003). He pointed out that only within a relatively narrow range of spatio-temporal scales can coarse sediment transport moving through fluvial systems be predicted with the aid of stochastic, deterministic and chaotic models. At longer time scales historically contingent explanation is appropriate. In other words, the concept of landscape connectivity is both spatial and temporal scale-dependent and conceptual framework-dependent. (Fig. 1).

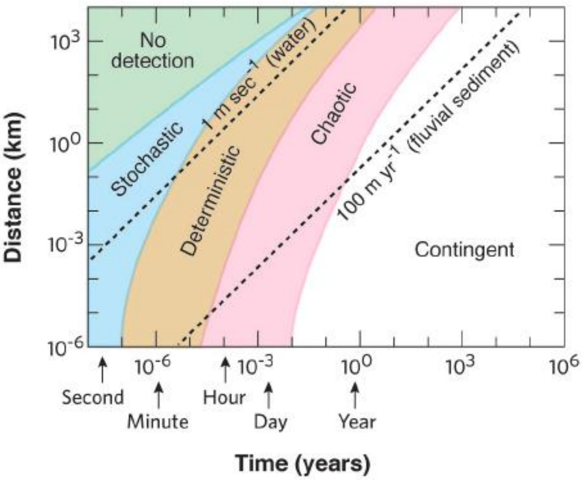

Fig. 1. Characteristic spatio-temporal domains of four modes of theory construction: stochastic, deterministic, chaotic and historically contingent. The relationships shown are specific to the virtual velocities of water and coarse sediment moving through fluvial systems (after M. Church 2003)

THE ANTHROPOCENE

The Anthropocene epoch has been proposed as a new division of geological time that acknowledges the now dominant role of humans as geomorphic agents (Crutzen, Stoermer 2000). A geomorphology that is concerned "only" with energy and mass fluxes in and around landforms (Haff 2010) promises to be ineffective in seeking deeper understanding of changing landscapes modified increasingly by human activities (Rhoads 2006). In this new epoch, the assumption that "the sense of causality runs from the physical environment to its social impacts" (Hewitt 1983, p. 5) will require reevaluation. New disconnectivities that arise between landforms, landscapes, and people at all spatio-temporal scales disrupt many of our predictive models (Lisenby, Fryirs 2017; Slaymaker et al. 2020).

PREFERRED WATER PATHWAYS

Ever since hydrology became central to geomorphology (Horton 1945) the significance of water flows in drainage basins and, in particular, the continuity of these flows has been emphasized. The question of connectivity, as exemplified by blue line networks on topographic maps, was investigated in the form of drainage density variations (e.g. Chorley, Morgan 1962; Fig. 2). The authors speculated that rainfall intensity, runoff intensity, and relief might well be the dominant drivers of the contrasting drainage densities in the USA and UK (Fig. 2).

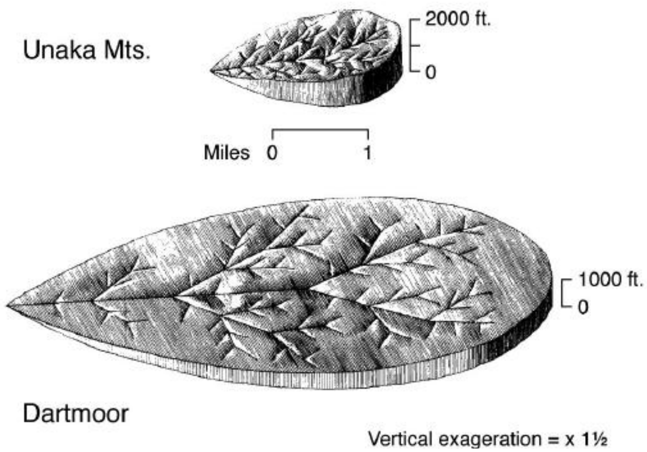

Fig. 2. Average drainage basin morphometry in A. the Unaka Mountains (USA) and B. Dartmoor (UK). Drainage density is the most obvious morphometric contrast between the two areas (Chorley, Morgan 1962)

On closer examination, it was soon realized that connections between headwaters and channel mouths exist only during short periods and intermittently (Gregory 1977). Gullies can be located on interfluves, in transitional zones or on footslopes and, depending on their spatial distribution, are, most of the time, unconnected in sub-humid seasonal climates (Bocco 1993). Riparian systems are a key component in ecosystem management in the Cuitzmala River basin in Jalisco, Mexico (Flores-Diaz et al. 2017). Small and medium scale riparian areas are distributed randomly through the basin; they buffer the impact of land use changes and play an important part in the regulation and functioning of the system (Fig. 3). This buffering effect is achieved by their patchy mosaic distribution and physical disconnectivity.

The Columbia Plateau lavas of Oregon, USA provide an instructive illustration of the structural and functional disconnectivity that exists between two lavas of differing age and permeability. The Western Cascade volcanic rocks are older, less permeable, and underlie the younger basalts of the High Cascades (Jefferson et al. 2006; Fig. 4). A series of large springs has developed at the boundary between the lavas of different age and permeability and the contrast has effectively partitioned hydrologic flowpaths between surface and sub-surface flow. (Jefferson et al. 2006). Landscape evolution in this basalt terrain is entirely constrained by the coupling and decoupling of surface and sub-surface flow (Grant et al. 2017).

APPROACHES TO QUANTIFICATION OF CONNECTIVITY

The availability of high resolution digital elevation models, high resolution LiDAR data, an ArcGIS toolbox and remote sensing data has given rise to an explosion of activity in the development of connectivity indices. Disconnectivity indices are less commonly discussed though conceptual frameworks that give equal prominence to connectivity and disconnectivity are available (e.g. Heckmann et al. 2018). Most of these indices conceptually consider an upslope (contributing area) and a downslope (source to sink) component to spatially describe the capacity of the catchment to export sediments. “Virtually all existing indices address the degree of static, structural connectivity only, with limited attention for process-based, functional connectivity counterparts” (Heckmann et al. 2018, p.77).

There are two categories of connectivity index: (1) landscape structural connectivity, relating to landscape history and morphology (Taylor et al. 1993); (2) hydrological and sediment functional connectivity: referring to the extent to which water and sediment fluxes through the landscape are facilitated (Lane et al. 2009; Lesschen et al. 2009; Bracken et al. 2015).

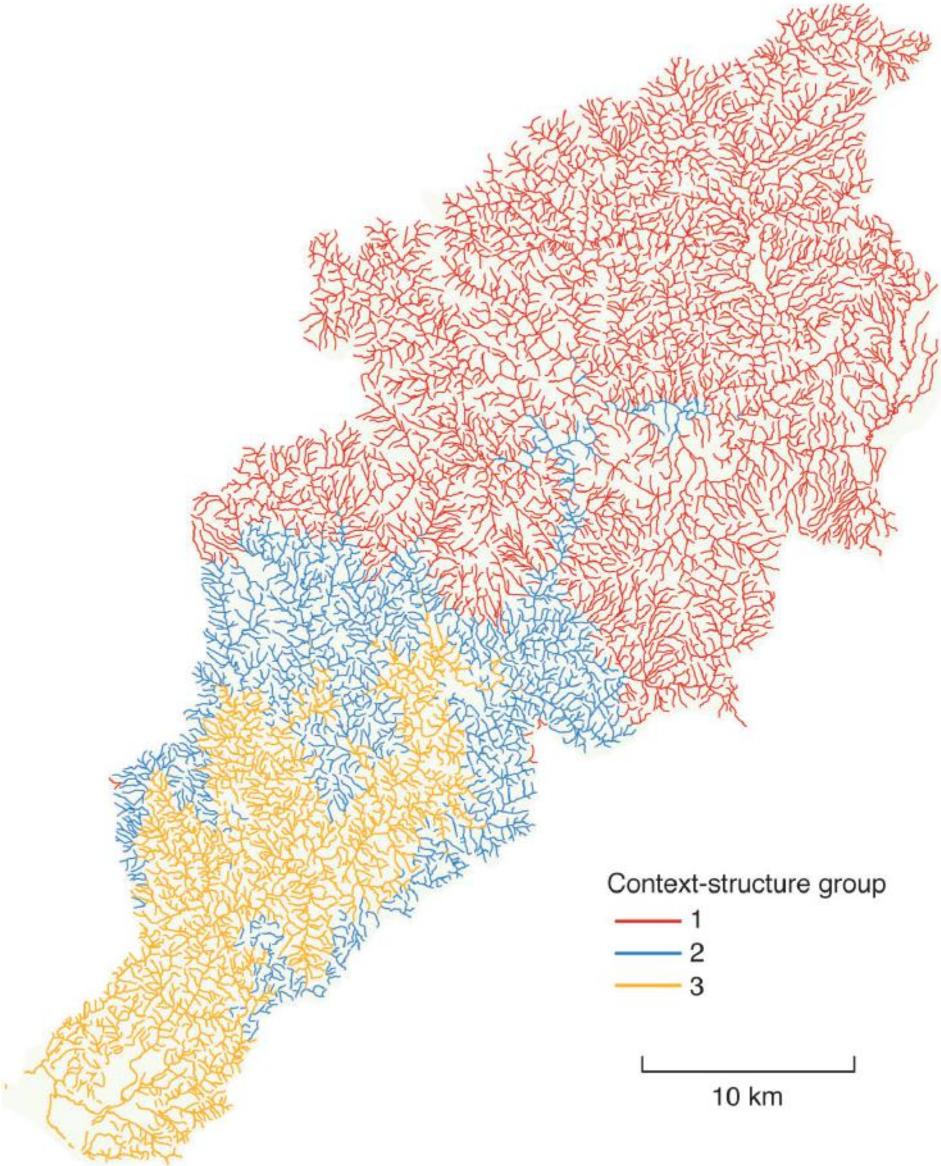

Fig. 3. Drainage basin morphometry and riparian research in Cuitzmala River basin, Jalisco state, Mexico. Note that the central part of the basin has a more or less random distribution of riparian areas by contrast with the upper and lower parts of the basin (Flores-Diaz et al. 2017)

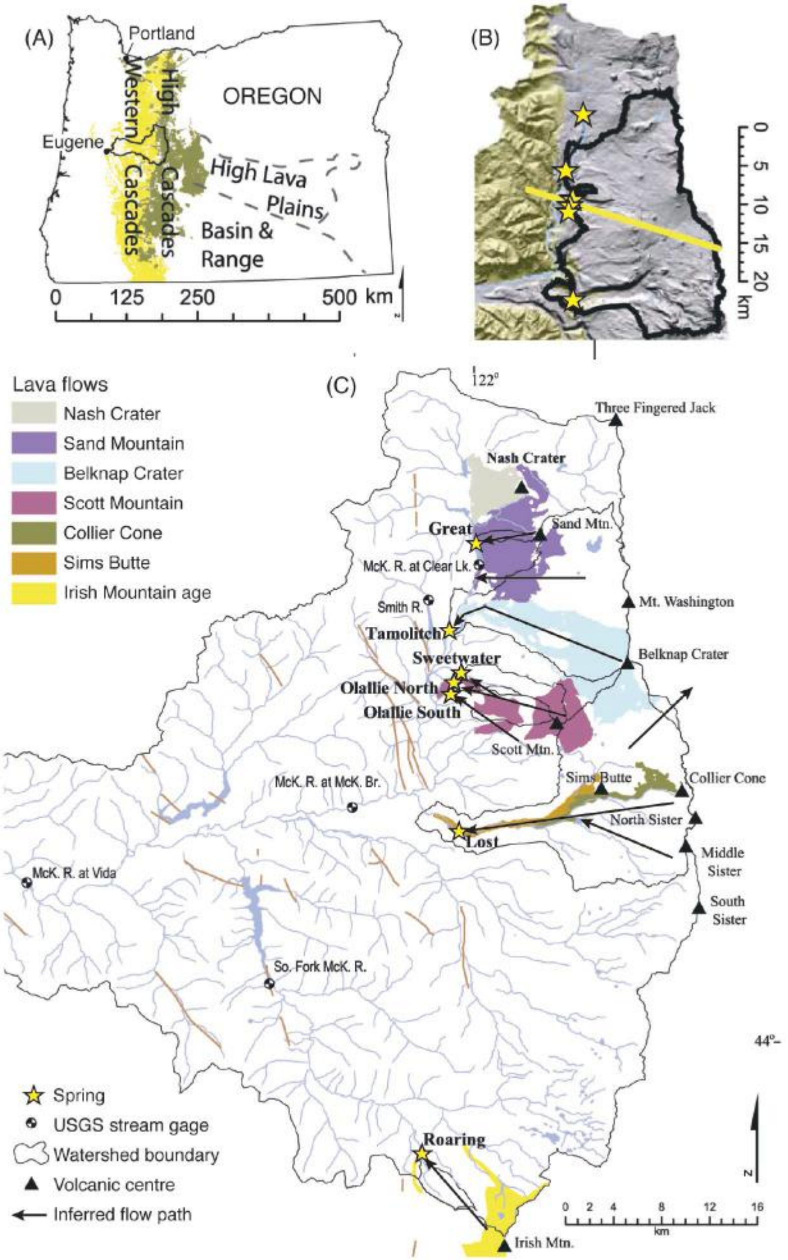

Fig. 4. Surface water versus groundwater preferred pathways on the western slopes of the; Oregon Cascade Range, USA. A. Extent of High Cascade and Western Cascade volcanic rocks in Oregon with McKenzie River watershed outlined in black; B. Upper portion of McKenzie River watershed showing the extent of the volcanic rocks (shaded) and locations of 6 of the 7 large springs (stars); C. The extent of individual lava flows as identified in legend and inferred groundwater flow paths (black arrows) (Jefferson et al. 2006)

STRUCTURAL LANDSCAPE CONNECTIVITY

Gradient, relief, aspect, terraces, erosion surfaces, terrain roughness, landforms, soil and vegetation cover are all implicated in landscape structure. Advantage can be taken of the improved precise mapping of landforms combining field observations, remote sensing and topographic modelling techniques (i.e. UAVs and automated digital photogrammetry) that has allowed determination of optimal threshold values for the different erosion processes. These indices are designed to quantify traditional qualitative approaches, which typically involve the interpretation of geomorphological maps and multiple field surveys (Harvey 2002; Brardinoni, Hassan 2007; Slaymaker et al. 2017; Cossart, Fressard 2017). Drainage channels are effective links to transfer runoff and sediment from the upper parts of a catchment to their outlet (Munro et al. 2008). But the presence of lakes and the construction of check dams increases catchment disconnectivity by disturbing sediment transfer routes.

HYDROLOGICAL AND SEDIMENT FUNCTIONAL CONNECTIVITY

Indices of connectivity are largely static quantitative representations of connectivity in catchment systems. They are strongly controlled by topography and take into account the characteristics of the drainage area and the flow path length that a particle travels to arrive at the target (e.g., a channel or the catchment outlet) (Cavalli et al. 2013). Sediment connectivity assessment and quantification is a challenge that occupies the minds of all process geomorphologists since (a) it cannot be measured explicitly (Turnbull, Wainwright 2019) and (b) the number of factors that can modify the sediment connectivity in a river system is very large. Sediment source description (e.g. river bed vs hillslopes) has been a central requirement of sediment budget studies at the catchment scale from their very inception (Dietrich, Dunne 1978; Bogen 1980).

A range of approaches, equations and models exists to assess erosion risk and to identify critical source areas within a catchment, including the revised universal soil loss equation (RUSLE) (e.g., Boggs et al. 2001). Many erosion risk models, which can be used in GIS software, require at a minimum data on land use, rainfall distribution and intensity and slope (DEM). Spatially explicit connectivity models of sediment transport from hillslopes to rivers are largely a function of the hillslope gradient, topographic ruggedness, and vegetation cover. A simple spatially distributed sediment delivery ratio (SDR) as defined by T. Heckmann and D. Vericat (2018) infers functional sediment connectivity by the computing of spatially distributed SDRs, defined as the ratio of total erosion measured on hillslopes and gullies to sediment load exported at the mouth of the river. This method results in a map with individual raster cells containing a calculated SDR value ranging between 1 (all eroded sediment exported) and 0 (all eroded sediment redeposited). An effective coupling between sediment sources and fluvial systems can lead to relevant sediment fluxes along the stream network, while disconnectivity can cause a discrepancy between erosion rates in the catchment and the amount of sediment exported from it (Munro et al. 2008; Poesen 2018). Each geomorphic process has a distinctive threshold at which it becomes active. (Harvey 2002; Wohl 2017).

Although these technical developments are important, much experimental work to validate the models used remains to be done. A summary note would suggest that we are at a similar stage in evolving connectivity indices as we were with respect to the modification of the Universal Soil Loss Equation C factor forty years ago (Wischmeier, Smith 1978).

SEDIMENT STORAGE AND FLUXES

Whenever sediments are added to the water fluxes in a geomorphic system disconnectivity in space and over time becomes a more central consideration than connectivity. Given that water fluxes without sediments are of relatively little interest to most geomorphologists, this observation enhances the importance of disconnectivity in geomorphic systems.

STORAGE SITES THAT ENHANCE GEOMORPHIC SYSTEM DISCONNECTIVITY

At the scale of the Mackenzie basin (1.6 million km^2) disconnectivity is largely a function of geological structure and physiography. Three physiographic megaregions are represented within the basin: the Cordillera, the Interior Plains and the Shield (Fig. 5). Shield tributaries of Mackenzie River that debouch from Great Bear, Great Slave and Athabasca lakes (70,000 km^2 in area) carry little sediment. All left bank tributaries of Mackenzie River have their sources in the Cordillera and flow across the Interior Plains, but the Athabasca and Peace River sediments are intercepted by the Peace-Athabasca delta and Williston Lake (dammed) before they enter Mackenzie River. Almost all of the c.130 million tonnes of sediment contributed annually to the Mackenzie delta derive from the Liard, the Peel and a large number of smaller tributaries from the Cordillera. The large lakes, reservoir and Peace-Athabasca delta disconnect the southern half of the basin from the northern half (Slaymaker 2020) such that disconnectivity characterizes Mackenzie basin sediment fluxes more effectively than connectivity.

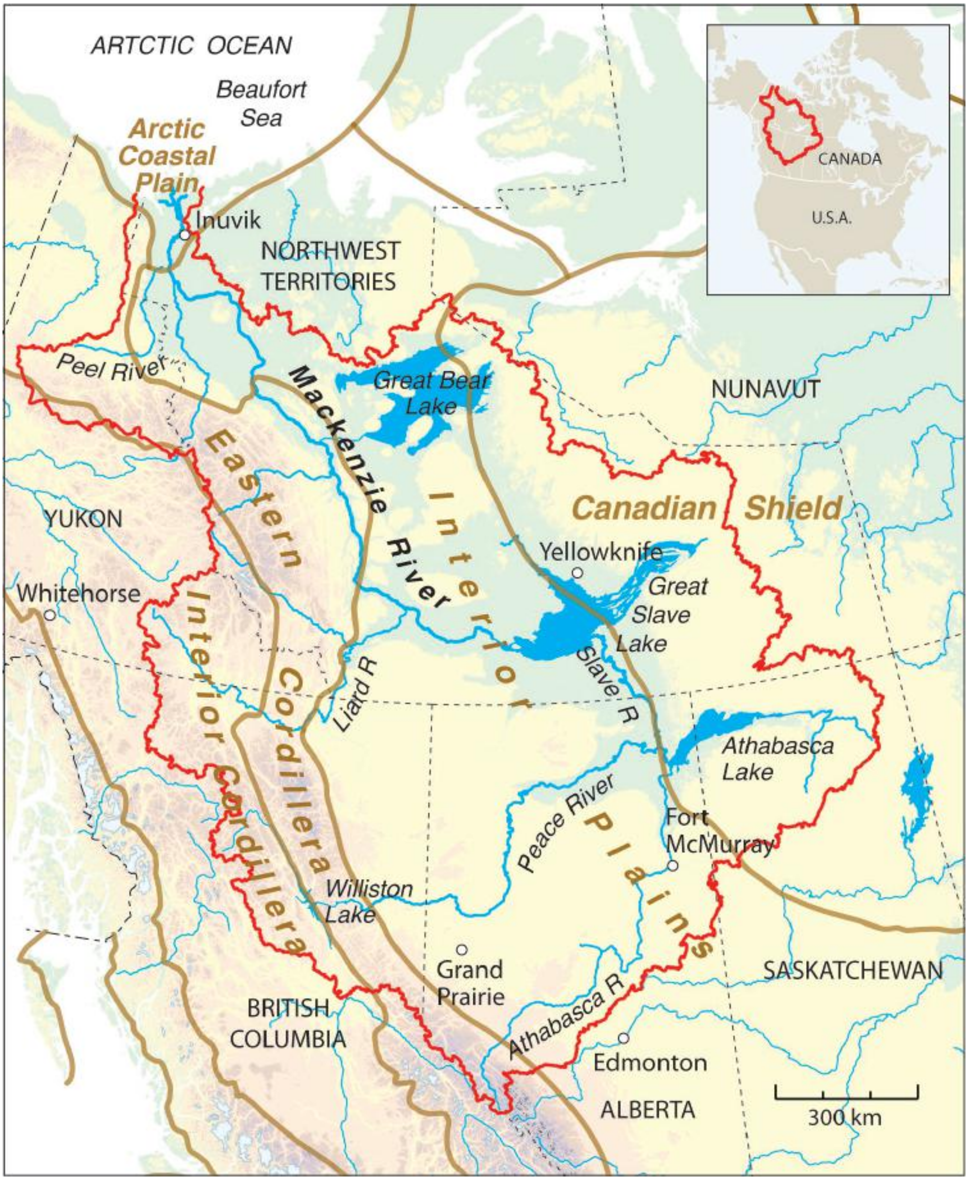

Fig. 5. Mackenzie River basin at 1.6 million km^2 is the largest river basin in Canada and discharges approximately 132 million tonnes of sediment per year. Note the exceptionally high percentage of large lakes (c. 70,000 km^2 or 4.4%) that disconnect the upper part from the lower part of the basin (from O. Slaymaker 2020)

At much smaller scales, suspended and solute sediment fluxes from the proglacial zone of the retreating Obersulzbachkees glacier, Hohe Tauern, Austria are strongly controlled by the presence of proglacial lakes (Geilhausen et al. 2013). Three glacierized basins in Norway have been shown to have totally different sediment budgets because overdeepened bedrock basins define the locations of proglacial lakes. Despite an anticipated increase in sediment yield from the retreating glacier, little sediment passes these lakes and downstream sediment delivery is reduced markedly (Bogen et al. 2015).

Globally, sandurs are typically located at the heads of fjords and in proglacial sites. Sandurs provide disconnectivity in space and jokulhlaups produce disconnectivity through their intermittent occurrence over time. The state of understanding of glacial lake outburst floods was summarized by T. Heckmann et al. (2016). Jokulhlaups figured prominently in proglacial landscape change at Solheimajokull in southern Iceland from 1960–2010 (Staines et al. 2015).

The Karakoram Himalayan region of Pakistan has some of the finest examples of disturbance regimes in which massive mass movements have generated disconnectivity over periods from centuries to millennia (Fig. 6). Catastrophic rock failures produce a distinctively fragmented drainage system (Hewitt 2006). Mapping massive alluvial and colluvial fans that interrupt the free flow of the Kali Gandaki River has demonstrated these major disconnectivities (Fort et al. 2010).

Fig. 6. Disconnectivity created by the large, prehistoric Dhumpu-Kalopani rock avalanche in the Nepal Himalayas (photo by Monique Fort, Cambridge University Press)

Contemporary debris fan accumulations in mountainous areas also provide detailed chronology of changing disconnectivities over time. For example, radiometric dating, stratigraphic analysis, fan morphology and basin morphometry were used to investigate semi-continuously active debris flow fans in the

North Cascade Foothills of Washington State, USA. Seven millennia of records from 12 drainage basins (0.3–33 km^2) reveal no discernible trend because the spatial and temporal variability of the events recorded is high. Disconnectivity seems to be a permanent feature of these basins (Kovanen, Slaymaker 2008). The Lillooet River basin in BC's Coast Mountains produces larger debris avalanches and debris flows with high frequency and magnitude (Fig. 7). For example, on August 6, 2010, the southwest flank of Mount Meager collapsed into Capricorn Creek, generating a debris flow of 48 million m^3 (Slaymaker et al. 2017) The context for this high magnitude mass movement is considered further in section 5.1 below.

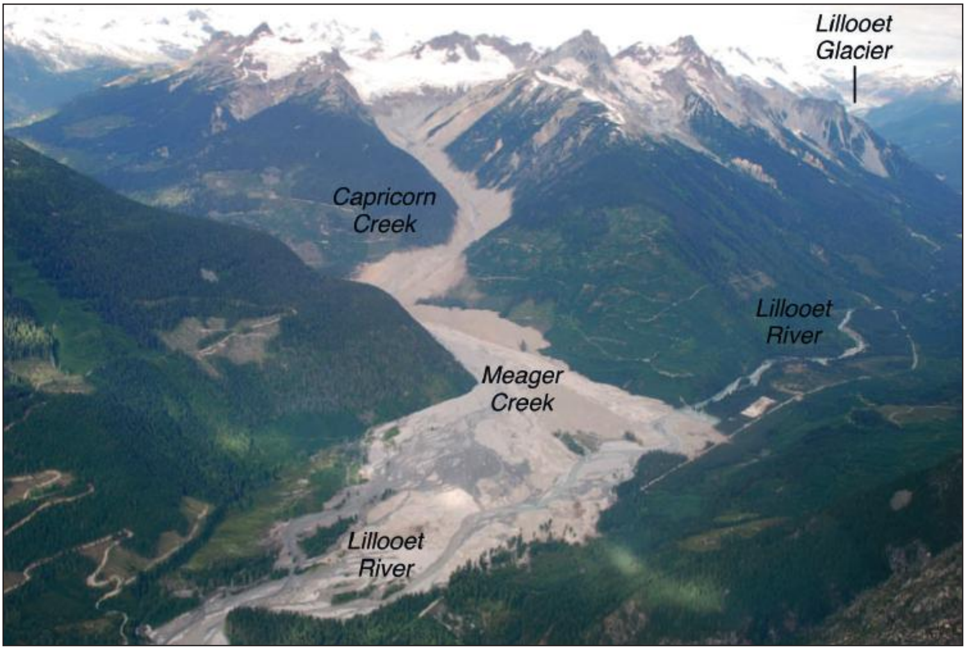

Fig. 7. Connectivity in the 2010 Capricorn debris avalanche and debris flow in the Mount Meager Volcanic Complex, Pacific Ranges of the Coast Mountains, British Columbia (oblique photograph taken on August 29, 2010 by John Clague) (Slaymaker et al. 2017)

In formerly glaciated regions, paraglacial fans and deltas are evidence of the major disconnectivity provided by accelerated sedimentation following the Last Glacial Maximum in western Canada (Church, Slaymaker 1989). The Fraser Lowland is a mosaic of glacimarine, marine, glacilacustrine, lacustrine, glacifluvial, fluvial and aeolian sediments and landforms that together constitute a very large (c. 5,000 km^2) paraglacial landsystem. Sediment flux combined with significant relative sea level change marked a major discontinuity in space and over time to produce this mosaic of landforms. (Kovanen, Slaymaker 2015).

DISTURBANCES BY HUMAN ACTIVITIES, SPECIFICALLY FOREST HARVESTING

Forest harvesting activities in small watersheds in the Queen Charlotte Ranges on Haida Gwaii off the west coast of Canada have severely disturbed stream channels (Fig. 8). Although contemporary harvest regulations prohibit in-stream and cross-stream harvesting, the impact has been observable for decades. Four small, steep drainage basins (3.9–12.6 km^2 with average gradient 0.18–0.12 and basin relief 490–910 m) were examined in the early 1980s (Roberts, Church 1986). The middle and downstream reaches of the main stem channels were found to contain accumulations of gravel, termed sediment wedges, of the order of 1 km in length. The development of these sediment wedges is a specific example of disconnectivity associated with poor land management practices. Sediment transport through the channels has increased by up to 10 times; however, the residence time for the in-channel sediment has increased by up to 100 times. Interestingly, the full extent of the disturbance is therefore observable only in the middle and lower reaches of the watersheds and provides an example of ways in which disconnectivity can provide resilience in the face of frequent disturbance.

Two watersheds in the Cascade Ranges of Oregon, USA with a combined area of 187 km^2 and a watershed relief of 1,290 m a.s.l. have been monitored for the effects of stream network structure and forest harvest practices over 50 years (Nakamura et al. 2000). Ecological disturbances range in severity from effects of debris flows, which completely remove colluvium along steep, narrow low order channels to localized patches of trees toppled by floating logs along the margins of larger channels. Because disturbances by human activities have become so much more common land use changes can affect the frequency and spatial pattern of events and the quantity and size distribution of material removed. Mountain mass fluxes can be envisaged as a cascade of disturbance processes that alter stream and riparian geosystems (Fig. 9). The affected stream and riparian landscape can be viewed through time as a network containing a shifting mosaic of disturbed patches. Linear zones of disturbance are created by the cascading geomorphic processes (Benda et al. 2004). These stream and riparian systems face frequent and large, widely distributed disturbance cascades. They are stream and riparian systems that impose a kind of disconnectivity that also promotes landscape resilience.

Hydrological and sediment disconnectivity has had a major impact on river channel response in the drainage basin of the Deleg River (88 km^2) in the Ecuadorean Andes. (Vanacker et al. 2005). The overall land use did not change significantly over four decades but the spatial pattern of the land use/cover did change. Although afforestation and regeneration of bare gully slopes

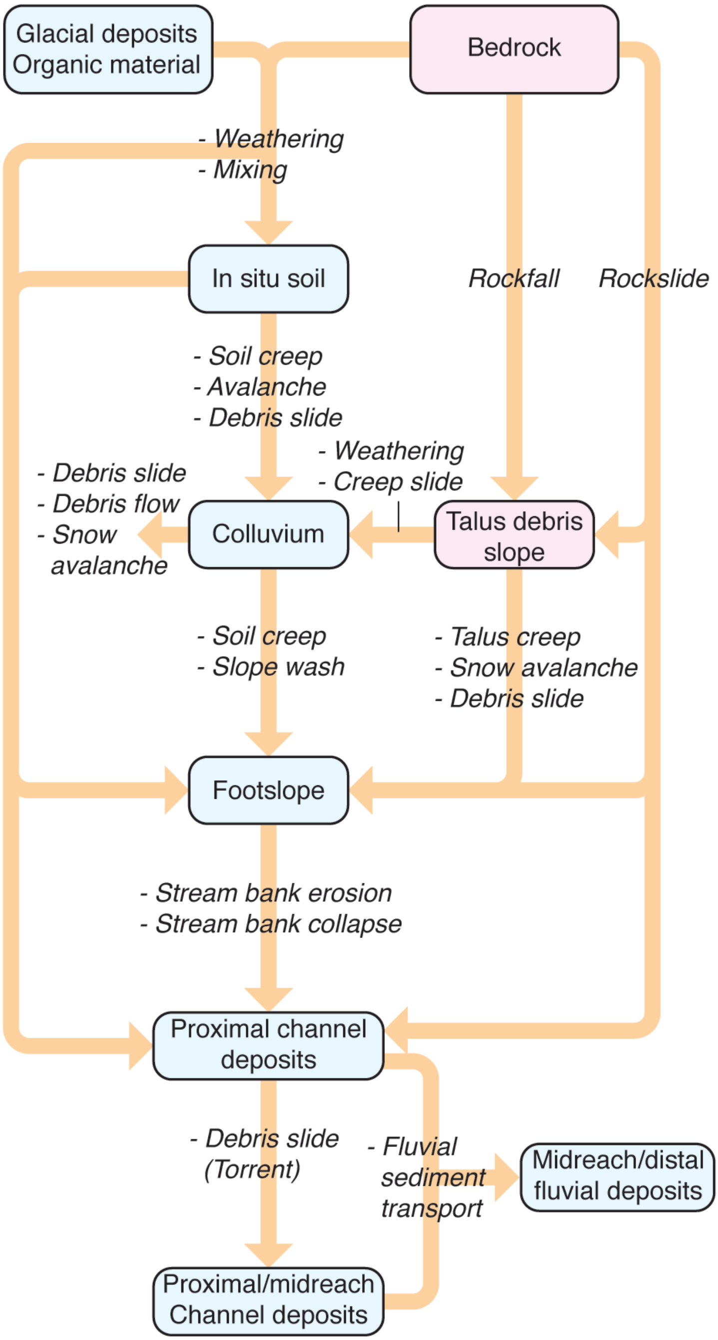

Fig. 8. Conceptual model of sediment flux in small steepland watersheds in the Queen Charlotte Ranges of Haida Gwaii, British Columbia. Boxes indicate principal reservoirs; the principal processes are in upper case letters (after R.G. Roberts and M. Church 1986)

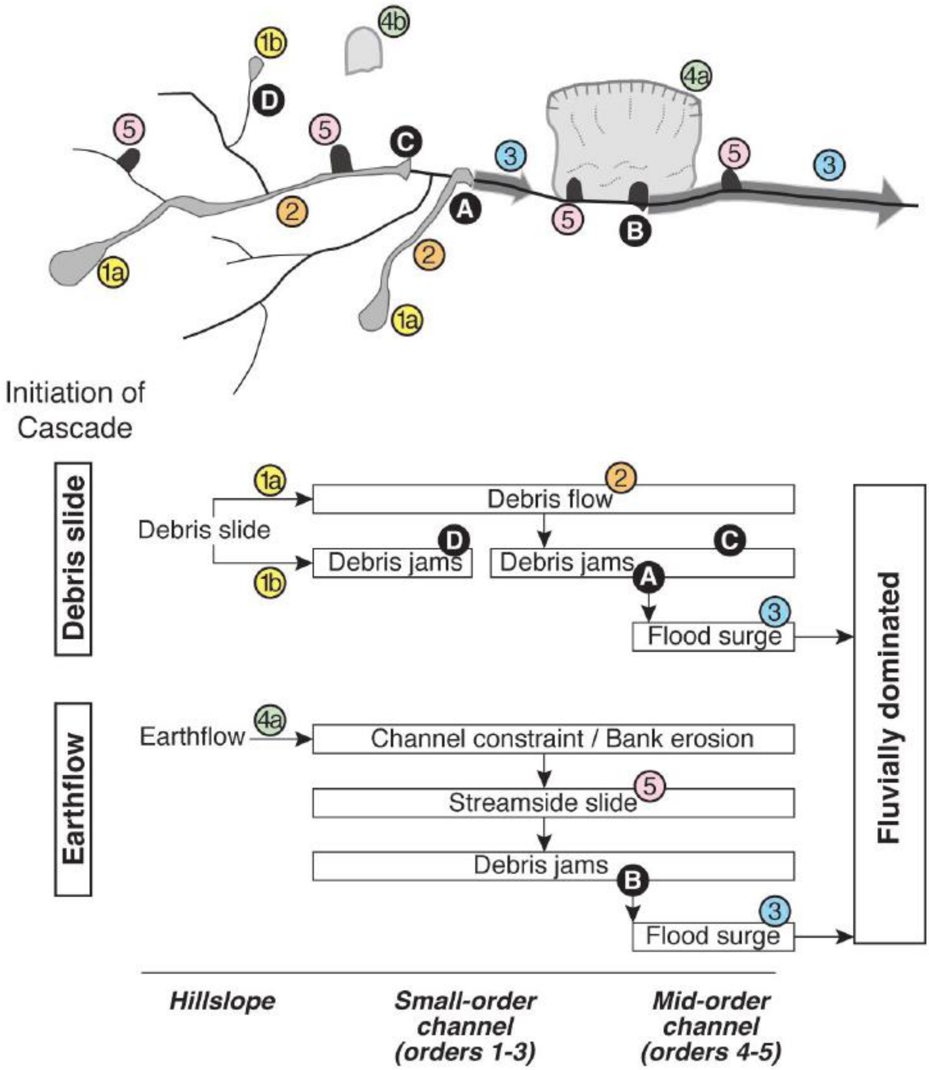

Fig. 9. Basin-wide disconnectivity within disturbance cascades in the upper Blue River basin, Cascade Ranges, Oregon, USA. Log and debris dams at sites A, B, C and D (Nakamura et al. 2000)

throughout the catchment only represented a minor part of the total land use changes the spatial organization of the changes was critical and is a third, but different, example of the additional resilience provided by human activity.

PROCESS DOMAINS AND DISCONNECTIVITY

CHARACTERIZING DRAINAGE BASINS BY DOMAINS OF DISCONNECTIVITY

The various morphological elements in the glacierized Lillooet-Harrison River basin (7,870 km^2) in the Pacific Ranges of British Columbia have been mapped according to the extent of their coupling to (or connectedness with) the mainstream river (Slaymaker et al. 2017; Fig. 10).

Five geomorphic systems that differ in degree of coupling are:

– Ridge tops that are coupled to the valley primarily through water and dissolved solids moving along sub-surface pathways. Clastic sediments are commonly decoupled on ridge tops.
– Hillslopes that are subject to infrequent large mass movements are episodically coupled.
– Debris avalanches and debris flow channels that directly but only intermittently couple ridge tops with valley bottom). This debris flux connects ridge tops and valley bottom when active but debris flows and adjacent hillslopes are rarely and only intermittently connected.
– Sediment storage that occurs in alluvial and colluvial fans and aggrading rivers that are intermittently coupled.
– Floodplain and lake sediment reservoirs that are frequently coupled.

Each component of the sediment cascade has a different level of disconnectivity within the geomorphic system (Fryirs, Brierley 2013). There are self-evident discontinuities in sediment production, transport and deposition (Baartman et al. 2013). Geochemical surface lowering processes on the one hand are distributed widely (Church et al. 2006) but extreme landslides, on the other hand, are highly localized (Korup et al. 2007).

GEOMORPHIC PROCESS DOMAINS

Geomorphic process domains and corresponding topographic signatures are defined by plotting local slope versus drainage area on logarithmic scales. The term is commonly used to define spatial associations of geomorphic processes within which one process dominates or profoundly affects the detachment and transport of mass (Brardinoni, Hassan 2007). Clastic sediment budgets within stream reaches (Hassan et al. 2010); rivers in which sediment flux is dominantly clastic (Miao 2010) and upland gravel bed rivers (Raven et al. 2010) are a few examples of the use of process domain analysis. The organization of channel reach morphology in a formerly glaciated landscape can be well represented as a function of degree of coupling, geomorphic process domain and hydrologic regime (Brardinoni, Hassan 2007).

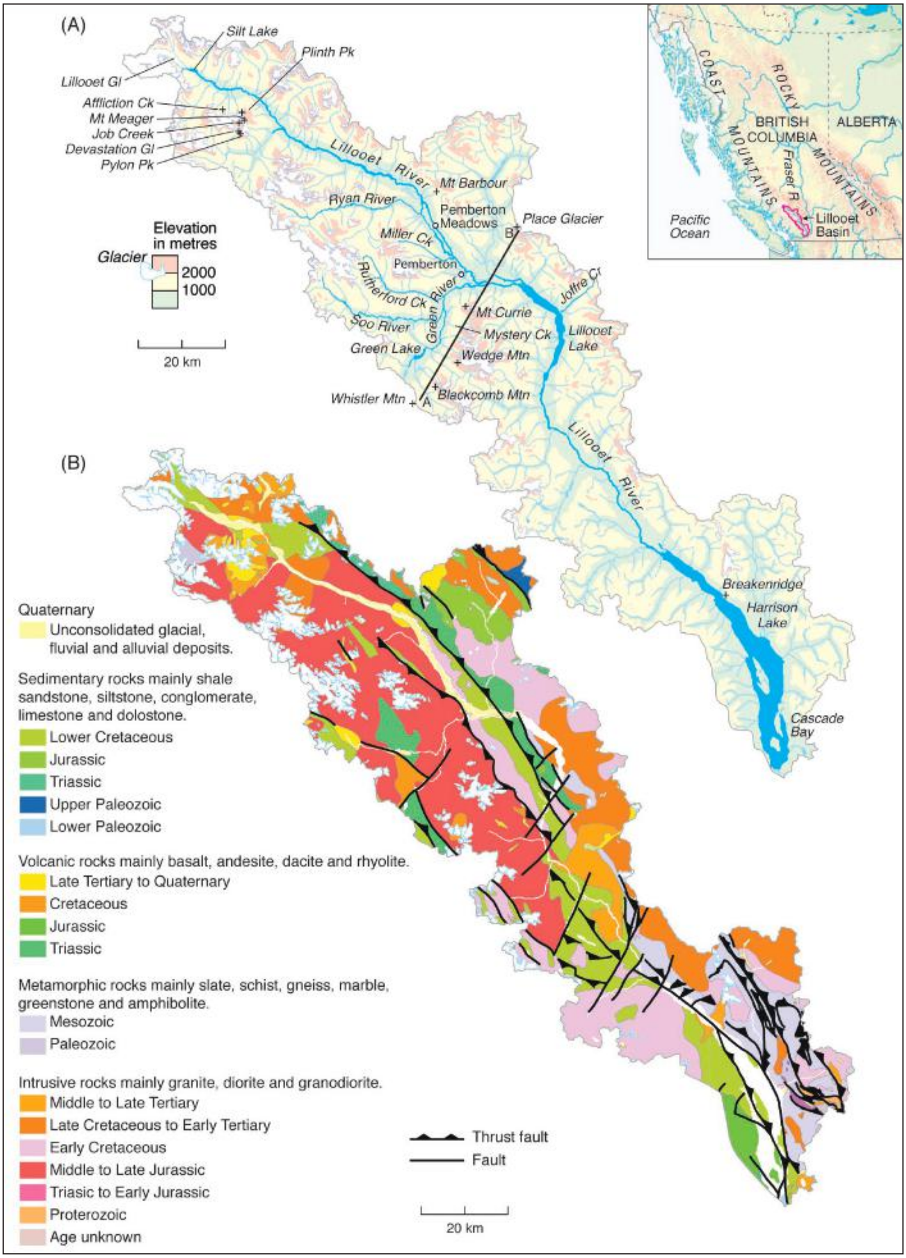

Fig. 10. Water, sediment and dissolved solids flux in Lillooet-Harrison River valley, Pacific Ranges of the Coast Mountains, British Columbia. A. The water and dissolved solids flux connectivity from Lillooet Glacier to the mouth of Harrison Lake contrasts with the sediment flux disconnectivity; B. Equally important is the sediment source disconnectivity between the Late Tertiary-Quaternary volcanic sediment source at Mount Meager through Jurassic intrusives and sedimentary rocks to the Quaternary unconsolidated glacifluvial and fluvial sediments of the valley bottom (Slaymaker et al. 2017)

Understanding the spatial patterns of geomorphic process domains is fundamental for problems of landscape evolution, aquatic ecology, conservation biology and river restoration (Montgomery, Foufoula-Georgiou 1993; Montgomery 2007). Sediment yield in fluvially dominated mountains is systematically scaled in the landscape; that is to say there is a well defined relation between drainage basin area and specific sediment yield. In formerly glaciated mountain drainage basins of coastal British Columbia, the complex, glacially induced channel long profile produces characteristic sequences of channel reaches that depart from the downstream succession (colluvial/boulder-cascade/step-pool/rapids/riffle-pool) distinctive of simple unglaciated mountain streams (Brardinoni, Hassan 2007) (Fig. 11). In tectonically active mountains and mountains heavily perturbed by human activity the well-defined relationship between basin area and specific sediment yield in fluvial systems also ceases to hold (Collins, Montgomery 2011) and disconnectivity prevails.

Geomorphic process domains			
Source colluvial	Hanging fluvial	Sink colluvial	Distal fluvial
Coupled	Decoupled	Coupled	Decoupled
Seasonal hydrologic regime	*Perenial hydrologic regime*		

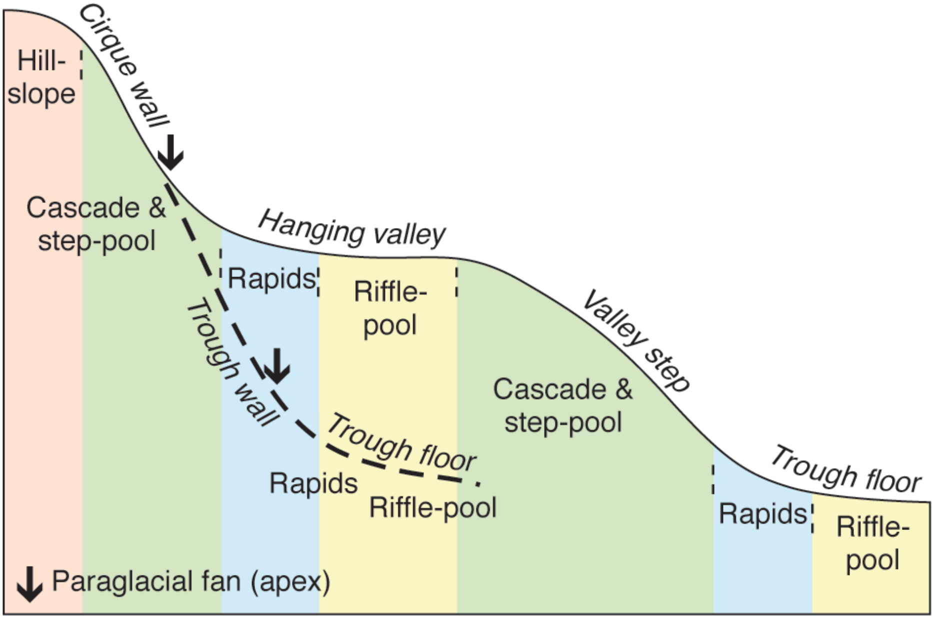

Fig. 11. Glacially induced organization of channel reach morphology in Capilano and Tsitika river basins, Pacific Ranges of Coast Mountains and Peninsular Ranges, Vancouver Island, British Columbia (Brardinoni, Hassan 2007)

Different perturbations of sediment storage areas produce multiple scaling (Church, Slaymaker 2016; Fig.12). This information was achieved by plotting drainage basin area versus specific sediment yield and superimposing the process domains determined from field observation and measurement (Church, Slaymaker 2016). This multi-scaled sediment yield model implies:

– Suspended sediment yield data can be validly classified into glacierized, glaciated and non-glaciated landscapes;
– Different patterns of aggradation, degradation and uniform yield can be expected at different spatial and temporal scales according to the dominant processes of sediment mobilization and deposition;
– Different patterns can be expected depending on the first and second order controls of specific sediment yield; and
– Different patterns will result from different kinds of disturbances and from different locations in each drainage basin where those disturbances are applied. This general semi-quantitative model is valid for most glaciated and glacierized landscapes.

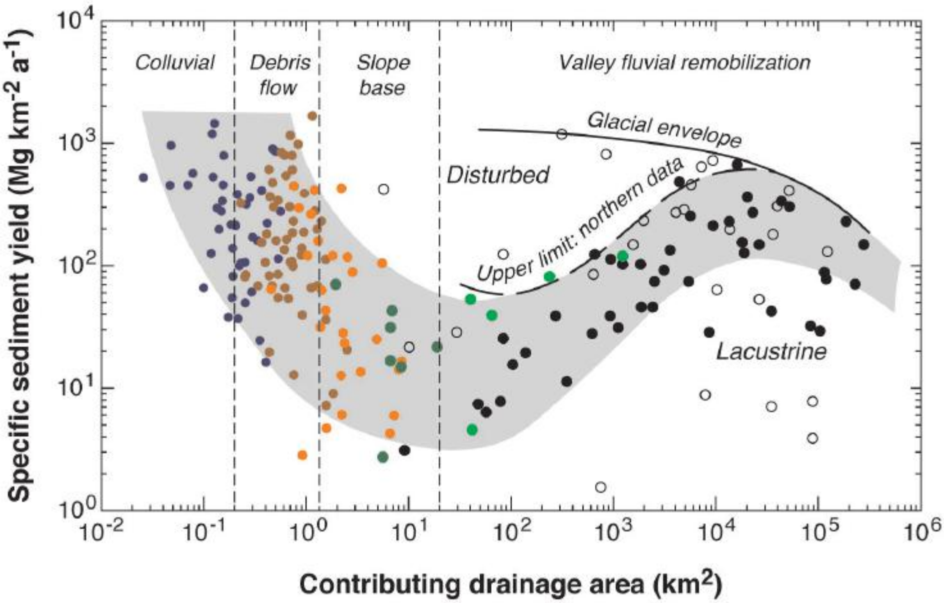

Fig. 12. Pattern of sediment yield and process domains in the glaciated Western Cordillera of British Columbia (Church, Slaymaker 2016)

CONCLUSIONS

Both spatial and temporal disconnectivity seems to be a more common characteristic of geomorphic systems than connectivity. The notable exception to this generalization is that of hydrogeomorphic systems, in which connectivity prevails to the extent that there is the common driver of flowing water. However, it is important to recognize that both connectivity and disconnectivity are not only temporal and spatial scale-dependent, but also conceptual framework-dependent.

Attempts to make geomorphology an exclusively predictive science are doomed to failure both because of the "unwelcome" reality that it is a centrally historical science (Chorley 1962, p. B3) and because, in this new Anthropocene epoch, the unpredictable effects of human decision-making are everywhere apparent in the landscape.

This is not meant to disparage the improved precision of quantitative indices that purport to measure connectivity following the availability of high resolution digital elevation models, high resolution LiDAR data, an ArcGIS toolbox and remote sensing data. This improved precision is of great practical value but does not necessarily solve any of the long-standing intellectual problems of our discipline.

Landscape systems globally are receiving new interpretations of morphology-process relations by interrogation of the idea of geomorphic process domains. Sediment cascade disturbances, decoupling and disconnectivities are highlighted by inflexions in the contributing area-slope relation and direct attention to the insufficiency of examining connectivity alone. Disturbances caused by both longer term geomorphological processes and short term land use changes produce disconnectivity in the landscape the recognition and analysis of which is also of applied significance in watershed management.

ACKNOWLEDGMENTS

The author acknowledges the generous comments of two anonymous reviewers and the critical review of an earlier version of the manuscript by Dr. D.J. Kovanen.

The author wrote this paper as a sign of his respect for the extraordinary contributions of Professor Leszek Starkel to the discipline of geomorphology, especially with respect to mountain geomorphology and landscape evolution during the Holocene. Congratulations, Leszek, on your 90th. anniversary!

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