

# WATS 5150 – Fluvial Geomorphology

## Instream Geomorphic Units (Form)



# Reading for this Module

- Chapter 8: Instream geomorphic units

## CHAPTER EIGHT

### *Instream geomorphic units*

#### Introduction

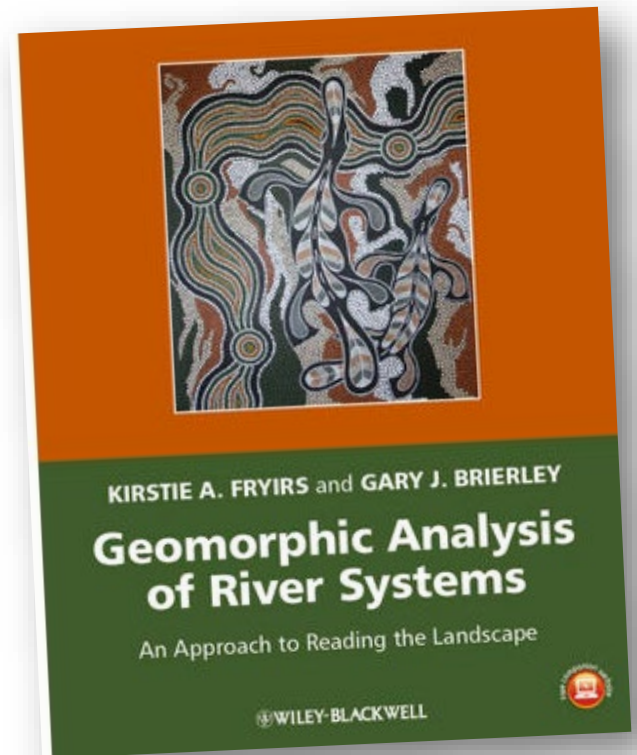
Patterns of erosional and depositional processes in river systems reflect the catchment-scale distribution of impelling and resisting forces, and resulting textural segregation, along longitudinal profiles (Chapter 3). Downstream transitions from imposed bedrock conditions in source zones to self-adjusting alluvial channels in accumulation zones reflect the shift from degradational to aggradational processes. This downstream trend is typically mirrored by progressive adjustment in valley confinement from confined to laterally unconfined valley settings. While incisional processes are dominant in steep confined settings of headwater streams, the wider valleys of low-relief lowland settings promotes dissipation of flow energy and differentiation of channel and floodplain processes and forms. This represents a shift in process domain from forced to fully alluvial rivers. Downstream trends from bedload through mixed-load to suspended-load rivers, and associated floodplain features are common (Chapters 6 and 9). These transitional relationships result in a range of landforms that are produced and reworked along valley floors. In this book, these erosional and depositional features are referred to as geomorphic units.

Geomorphic units are the building blocks of river systems. They are defined by their morphology (shape and geometry), sedimentary composition, bounding surfaces and position on the valley floor. Differentiation is made between instream (channel) and floodplain forms (Chapters 8 and 9 respectively). Erosional or depositional processes, or a range thereof, produce these features. Analysis of process-form relationships that generate and rework landforms can be used to interpret river behaviour. Processes affect the form, while the form affects the effectiveness of process relationships. These mutual interactions are referred to as morphodynamics. Correctly identifying a geomorphic unit and examining its form and sedimentology can be used to interpret the processes that form and rework that feature.

The availability of sediment and the potential for it to be reworked in any given reach determines the distribution of geomorphic units and resulting river structure. Some rivers comprise forms that are sculpted or eroded, reflecting a dominance of reworking processes. Other rivers comprise sets of geomorphic units that are the result of short- or long-term sediment accumulation. Characteristic forms are found at characteristic locations within river systems, at both catchment and reach scales. Geomorphic units are created by distinct sets of processes at different positions along a river course (i.e. erosional processes dominate in source zones, while depositional forms are dominant in accumulation zones). Within any given reach, distinct features are found at particular locations on the valley floor (e.g. point bars are found on the inside of bends, levees are found at channel margins).

Instream geomorphic units are found along a slope-induced energy and textural gradient. A continuum of features extends from high-energy erosional (sculpted) forms in bedrock and boulder settings to mid-channel depositional units and bank-attached forms. Forced units are produced when flow patterns and available energy are disrupted by obstructions such as bedrock, vegetation or wood that induce irregularities along the valley floor, thereby creating resistance. Sculpted forms may also be formed in low-energy, fine-grained settings. Unit features are products of single depositional events, whereas compound features reflect a range of flow conditions and reworking events. Inevitably, the pattern of features is intimately tied to channel geometry (shape and size; Chapter 7).

Characteristic assemblages of features analysed at the reach scale determine the character and behaviour of differing types of rivers (Chapters 10 and 11 respectively). Different features are formed and reworked at differing flow stages, dependent upon their position and elevation on the valley floor and how this affects the distribution and use of flow energy. Energy use varies with slope and confinement (and associated total/unit stream power; Chapter 5),



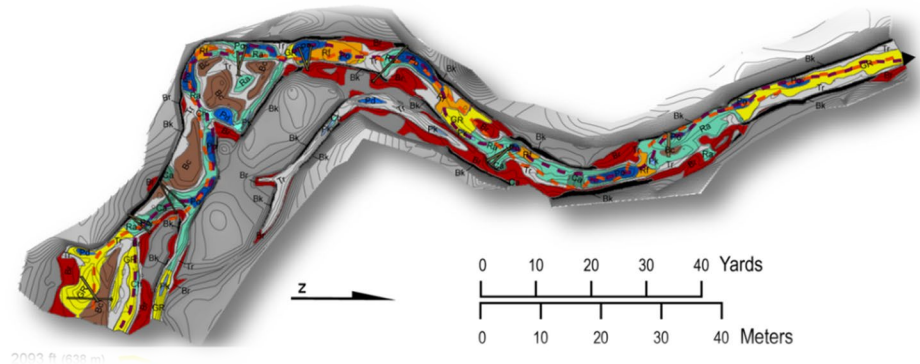
- Brierley G and Fryirs K. 2005. Geomorphology and River Management: Applications of the River Styles Framework. Blackwell Publishing: Victoria, Australia, 398 pp.



# Purpose of This Module

Geomorphology – *The study of **landforms** and processes that shape them.*

- Give you the skills for “Step 1” in reading Riverscapes
- Help you understand the **building blocks** of riverscapes (starting with in-channel geomorphic units)
- Introduce you to the tools and terminology to help you **read and map riverscapes**



Some of same content we cover in  
[WATS 6840 – Ecohydraulics](#) & [WATS 5350 – Restoration Capstone](#)

# Instream Geomorphic Units

- I. **Intro → Geomorphic Units & Process-Form Associations**
- II. Classification & Field Identification
- III. Your Book (River Styles)
  - I. Sculpted, Erosional Bedrock & Boulder GUs
  - II. Mid-Channel, Depositional GUs
  - III. Bank-Attached, Depositional GUs
  - IV. Sculpted, Erosional Fine-Grained GUs
  - V. Unit & Compound GUs
  - VI. Forced GUs
- IV. Continuum of GUs
- V. Fluvial Taxonomy GUs (Topographically Defined)
  - I. Tier 1 – Stage
  - II. Tier 2 – Shape / Form
  - III. Tier 3 – Attributed
- VI. GUT (Geomorphic Unit Toolkit)



# Reading Riverscapes

## Step One: Identify individual landforms (geomorphic units) and the process-form relationships that determine their process regime.

Identify the types of units in the channel and on the floodplain. Interpret the morphodynamics of each geomorphic unit based upon its process-form interactions, outlining the erosional and depositional processes that create and rework each feature.

## Step Two: Analyse and interpret the package and assemblage of landforms at the reach scale and how they adjust over time.

Analyse the range of units within a reach as packages of genetically linked assemblages, taking into account their position and their juxtaposition with other units. Appraise interactions between landforms by interpreting the erosional or depositional nature of boundaries (contacts) between units. Assess magnitude-frequency relationships that form and rework the package of landforms. These insights are combined to determine the behavioural regime (natural range of variability) of the reach.

## Step Three: Explain controls on the package and assemblage of landforms at the reach scale and how they adjust over time.

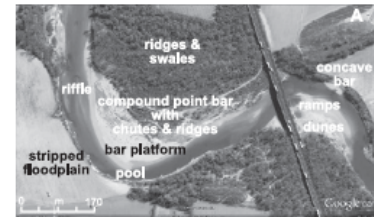
Analyse the range of flux and imposed boundary conditions that control the process relationships that characterize the behavioural regime of a reach. Assess natural (geological, climatic) and human-induced controls upon river behaviour and evolution. Explain contemporary landscape behaviour in relation to longer term evolution, framing system responses to human disturbance in relation to natural variability.

## Step Four: Integrate understandings of geomorphic relationships at the catchment scale.

Place each reach/site in its catchment context and examine linkages between compartments to interpret spatial relationships within that system. Examine downstream patterns of river types to assess why certain rivers occur where they do along longitudinal profiles, interpreting the dominant controls on river character and behaviour. Interpreting the efficiency and effectiveness of sediment flux at the catchment scale determines the strength of linkages (connectivity) in the catchment, and associated natural or human-induced responses to disturbance events (i.e. lagged and offsite impacts).

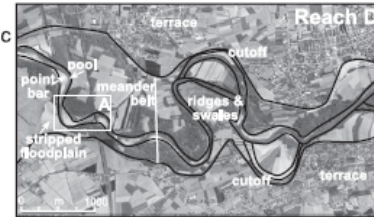
- It's a lot... that's why we'll take all semester learning it...

**Step 1: Identify individual instream and floodplain geomorphic units and determine their process-form relationships.**



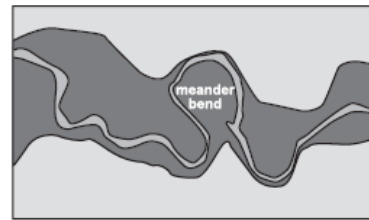
**Example of interpretation**  
*\*ridges & swales* formed by helicoidal flow forming scroll bars, concave bank erosion and channel migration  
*\*compound point bar* formed by deposition of gravel on the inside of a meander bend, flow realignment over the bar at bankfull stage and scour of chute channels. Sediment is deposited around vegetation to form ridges.

**Step 2: Analyse and interpret the assemblage of geomorphic units at the reach scale and how they adjust over time.**

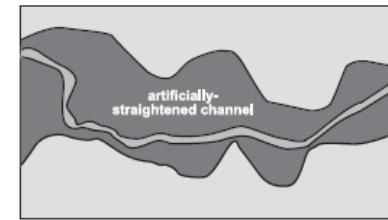


**Example of interpretation**  
*\*low flow stage* - flow aligned around bars and over riffles. Undercutting of concave bank occurs.  
*\*bankfull stage* - point bars are short-circuited, pools are scoured, riffles are deposited, concave bank erosion and deposition on convex bank leads to channel migration.  
*\*overbank stage* - flow aligned over the neck of meander bends, forming cutoffs

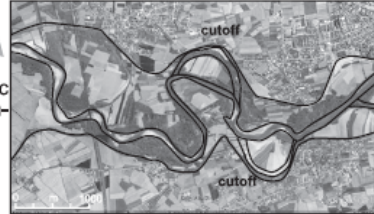
Past



Future



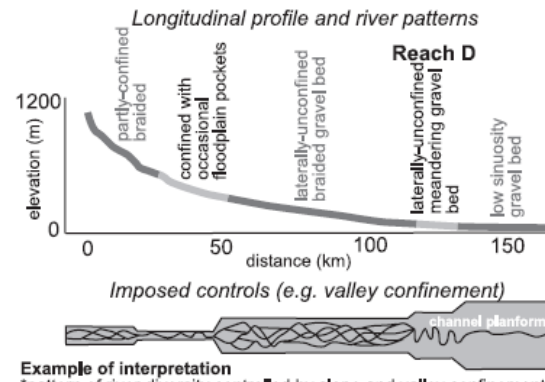
Present



**Step 3: Explain controls on the assemblage of geomorphic units, and 'natural' and human-induced impacts.**

**Example of interpretation**  
*\*flux controls* - transport-limited river with high sediment supply, Flashy flow regime.  
*\*imposed controls* - tectonic activity resets base level.  
*\*human impacts* - revegetation, cutoff formation and artificial straightening of channel.

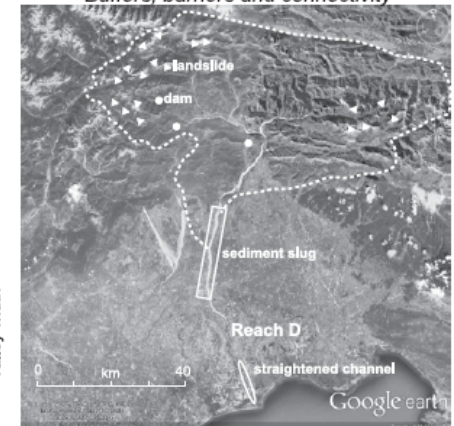
**Step 4: Integrate understandings of geomorphic relationships at the catchment scale.**



### Example of interpretation

*\*pattern of river diversity controlled by slope and valley confinement*  
*\*sediment supply is high due to landslide connectivity in headwaters*  
*\*role of disconnected tributaries varies over time (e.g. dams)*  
*\*channelised reaches convey sediment more efficiently*

### Buffers, barriers and connectivity



# Step 1 – Mapping Geomorphic Units

**Step 1:** Identify individual instream and floodplain geomorphic units and determine their process-form relationships.



## Example of interpretation

*\*ridges & swales* formed by helicoidal flow forming scroll bars, concave bank erosion and channel migration

*\*compound point bar* formed by deposition of gravel on the inside of a meander bend, flow realignment over the bar at bankfull stage and scour of chute channels. Sediment is deposited around vegetation to form ridges.

**Figure 1.4** An example of how to apply the reading the landscape approach to a real river system (See Colour Plate 1). The example used here is the Tagliamento River in Italy. The approach begins by interpreting process-form relationships for individual, then assemblages of geomorphic units along different reaches of river type. River behaviour is interpreted for a range of flow stages. The role of natural and human induced disturbance on river adjustments over time is considered when analysing river evolution. Finally, each reach is placed in its catchment context, analysing flux and imposed controls on river diversity along longitudinal profiles and how reaches to fit together in a catchment. Interpreting the efficiency of sediment flux at the catchment scale determines the (dis)connectivity of the catchment and associated off-site responses to disturbance. Maps constructed using Google Earth © 2012 images. Based on information in Bertoldi et al. 2009, Gurnell et al. 2000, Surian et al. 2009 and Tockner et al. 2003. The interpretation of river types, river evolution and connectivity are our own.



# Review...

- So all the earlier chapter stuff matters...
- They define geomorphic units as “erosional and depositional features”

## Introduction

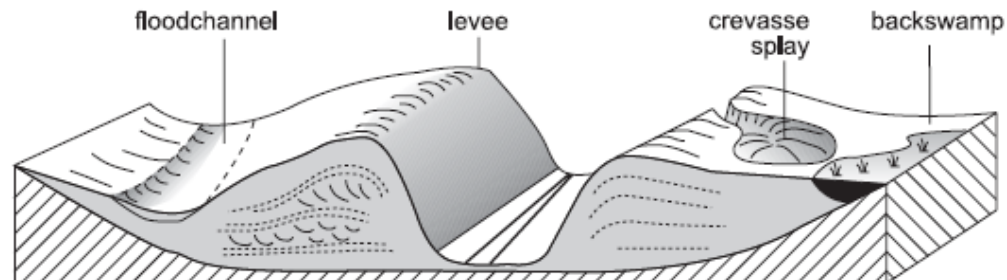
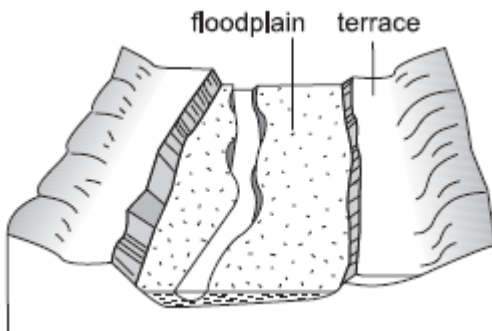
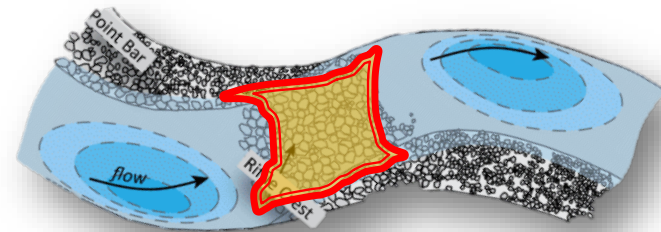
Patterns of erosional and depositional processes in river systems reflect the catchment-scale distribution of impelling and resisting forces, and resulting textural segregation, along longitudinal profiles (Chapter 3). Downstream transitions from imposed bedrock conditions in source zones to self-adjusting alluvial channels in accumulation zones reflect the shift from degradational to aggradational processes. This downstream trend is typically mirrored by progressive adjustment in valley confinement from confined to laterally unconfined valley settings. While incisional processes are dominant in steep confined settings of headwater streams, the wider valleys of low-relief lowland settings promotes dissipation of flow energy and differentiation of channel and floodplain processes and forms. This represents a shift in process domain from forced to fully alluvial rivers. Downstream trends from bedload through mixed-load to suspended-load rivers, and associated floodplain features are common (Chapters 6 and 9). These transitional relationships result in a range of landforms that are produced and reworked along valley floors. In this book, these erosional and depositional features are referred to as geomorphic units.

# Geomorphic Unit Definition

- A geomorphic unit is a landform that is a byproduct of erosion and deposition of sediment
- Fluvial geomorphic units are the result of fluvial (by water) erosion and deposition

For mapping purposes:

- GU's are spatially continuous areas that can be topographically defined
- GU's can be represented on a cell-by-cell basis by probabilistic or fuzzy membership in a class (e.g. probability of being a bar)
- GU's are often represented as mutually exclusive polygons, but can be mapped with points as well



Figures from: Brierley and Fryirs (2005)



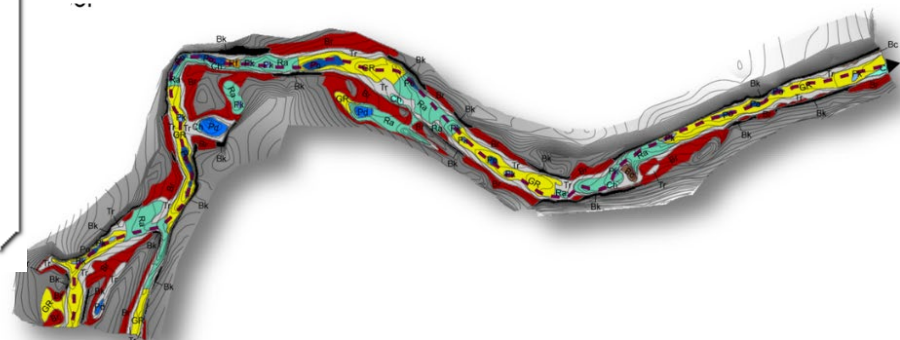
# Remember...

## Geomorphic Units are building blocks of the landscape

Geomorphic units are the building blocks of river systems. They are defined by their morphology (shape and geometry), sedimentary composition, bounding surfaces and position on the valley floor. Differentiation is made between instream (channel) and floodplain forms (Chapters 8 and 9 respectively). Erosional or depositional processes, or a range thereof, produce these features. Analysis of process-form relationships that generate and rework landforms can be used to interpret river behaviour. Processes affect the form, while the form affects the effectiveness of process relationships. These mutual interactions are referred to as morphodynamics. Correctly identifying a geomorphic unit and examining its form and sedimentology can be used to interpret the processes that form and rework that feature.

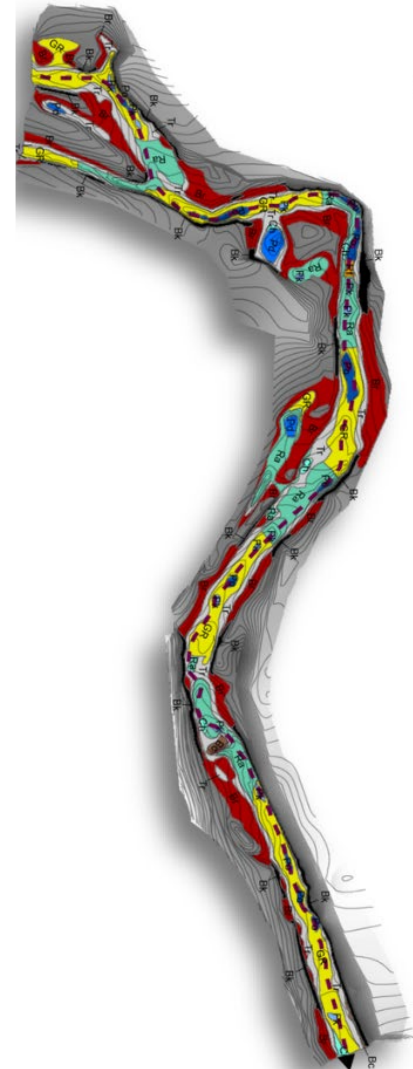
Fryirs & Brierley (2013)

DOI: [10.1002/9781118305454](https://doi.org/10.1002/9781118305454)



# Spatial Distribution of Geomorphic Units is Distinctive (not unique)

The availability of sediment and the potential for it to be reworked in any given reach determines the distribution of geomorphic units and resulting river structure. Some rivers comprise forms that are sculpted or eroded, reflecting a dominance of reworking processes. Other rivers comprise sets of geomorphic units that are the result of short- or long-term sediment accumulation. Characteristic forms are found at characteristic locations within river systems, at both catchment and reach scales. Geomorphic units are created by distinct sets of processes at different positions along a river course (i.e. erosional processes dominate in source zones, while depositional forms are dominant in accumulation zones). Within any given reach, distinct features are found at particular locations on the valley floor (e.g. point bars are found on the inside of bends, levees are found at channel margins).





# Forcing... and Notion of Unit vs. Compound

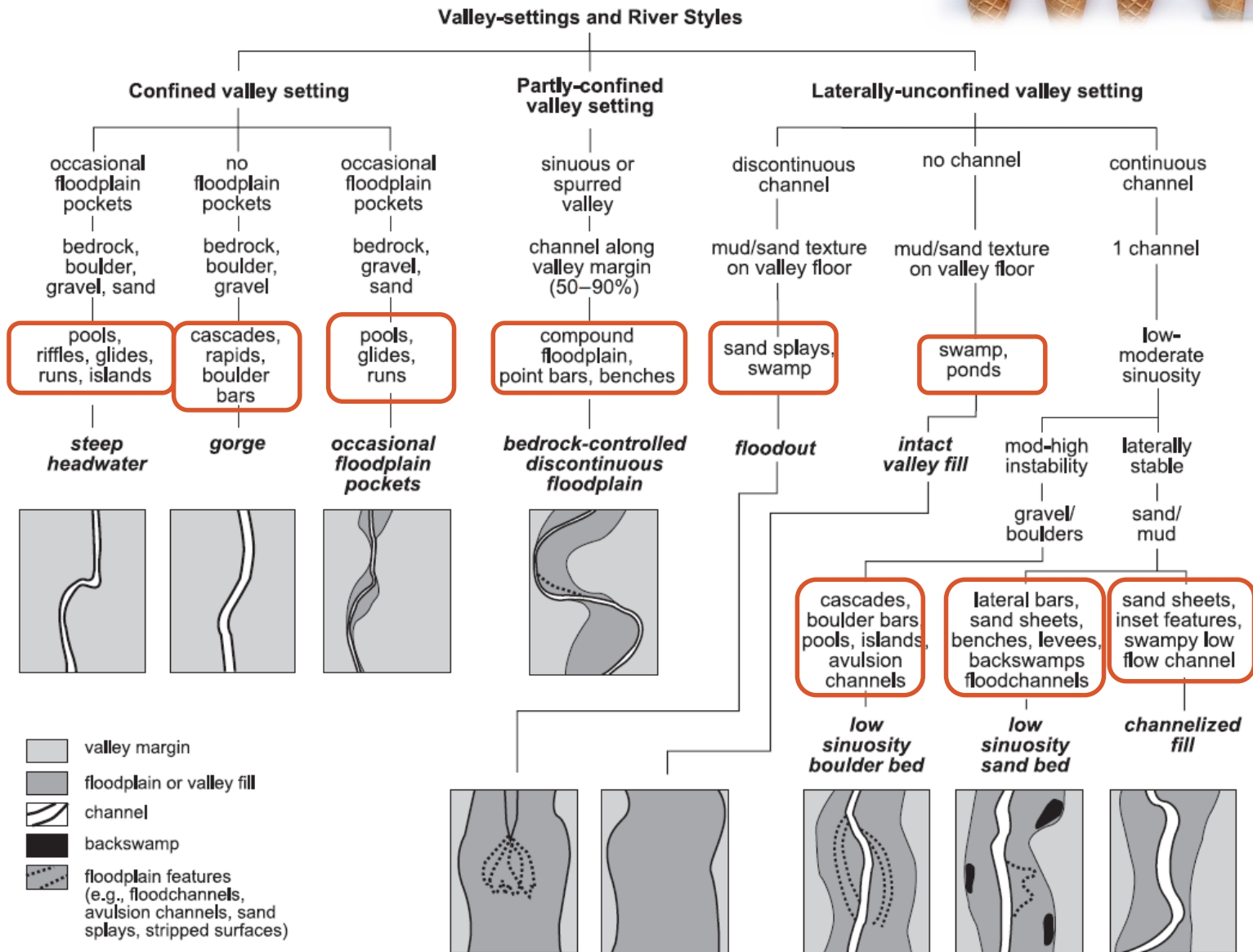
- Forcing (disruptions to hydraulics) by:
  - Structural Elements (wood, boulders, beaver dams)
  - Bedrock
  - Other geomorphic units
  - Planform
- Position matters
- Units – easy to identify when formed by single depositional events, vs. compound units reflect a range of flow conditions and reworking events

found at channel margins).

Instream geomorphic units are found along a slope-induced energy and textural gradient. A continuum of features extends from high-energy erosional **sculpted** forms in bedrock and boulder settings to mid-channel depositional units and bank-attached forms. **Forced units** are produced when flow patterns and available energy are disrupted by obstructions such as bedrock, vegetation or wood that induce irregularities along the valley floor, thereby creating resistance. Sculpted forms may also be formed in low-energy, fine-grained settings. **Unit features** are products of single depositional events, whereas **compound features** reflect a range of flow conditions and reworking events. Inevitably, the pattern of features is intimately tied to channel geometry (shape and size; Chapter 7).

**Characteristic assemblages** of features analysed at the reach scale determine the character and behaviour of differing types of rivers (Chapters 10 and 11 respectively). Different features are formed and reworked at differing flow stages, dependent upon their position and elevation on the valley floor and how this affects the distribution and use

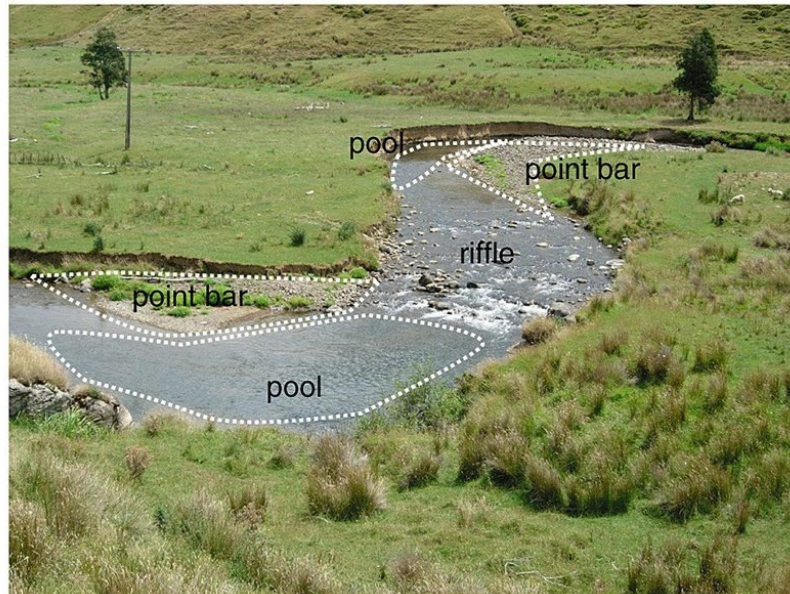
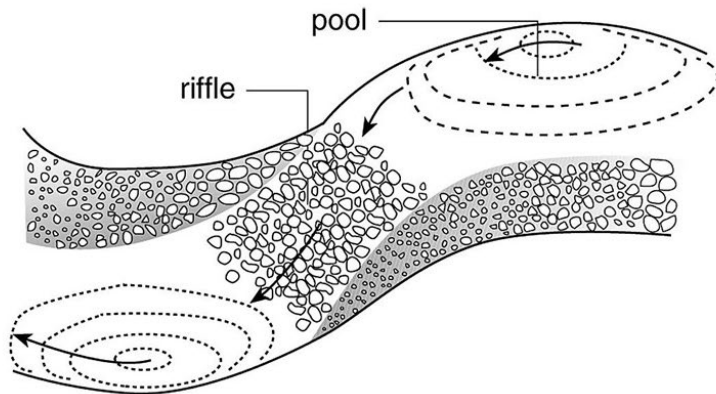
# River Styles Tree & Fruit?



**Figure 9.10** The Bega catchment River Styles tree (from Fryirs, 2001)



# Geomorphic Units can be “Genetically Linked”



Fryirs & Brierley (2013)

DOI: [10.1002/9781118305454](https://doi.org/10.1002/9781118305454)

sediment availability and calibre (Chapter 6) and hydrological considerations (Chapter 4). Many geomorphic units are *genetically linked*, whereby the processes that form or rework one feature affect the formation or reworking of adjacent units. For example, steps and pools tend to occur together along steep, bedrock-controlled rivers, whereas pools and riffles tend to occur together along meandering rivers. Differentiation of spatially and genetically connected or disconnected geomorphic units is a key attribute in analysis of river adjustment. Analysis of reach-scale patterns of geomorphic units enables interpretation of landscape evolution. For example, terrace features reflect a different phase of river activity relative to the contemporary floodplain or channel zone (see Chapter 12).

This chapter focuses on the *process–form associations* that generate and rework instream geomorphic units. Although individual geomorphic units may be observed along reaches in a range of river types (e.g. pools are common along many variants), specific ranges and assemblages of geomorphic units tend to occur along different types of rivers. Analysis of the full set of processes responsible for the formation of instream and floodplain geomorphic units facilitates interpretations of *river behaviour* at different flow stages. *Appraisal of river character and behaviour based on assemblages of geomorphic units can be viewed as a building block, or a constructivist approach, to analysis of river systems.*



# If I Took You to an Overlook...



- And I asked you to draw a map...
- What would you draw?

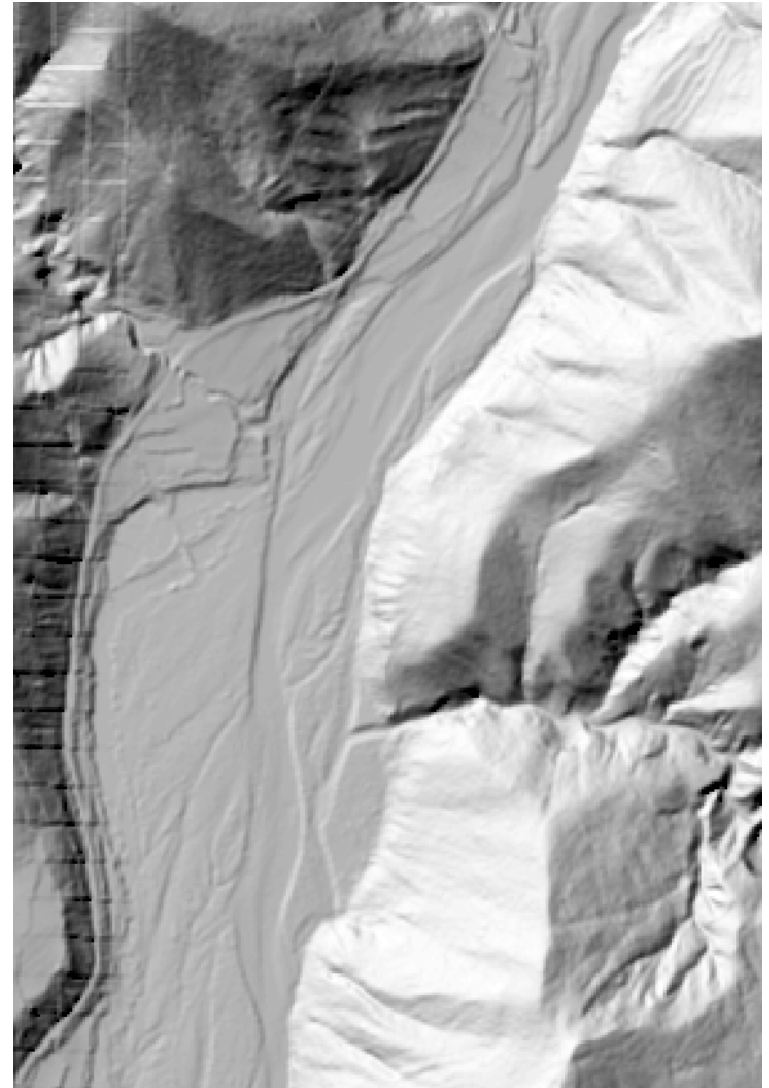




# For Real, What Would You Draw?



- If I gave you an aerial photo?



- Would you draw something different from a DEM?



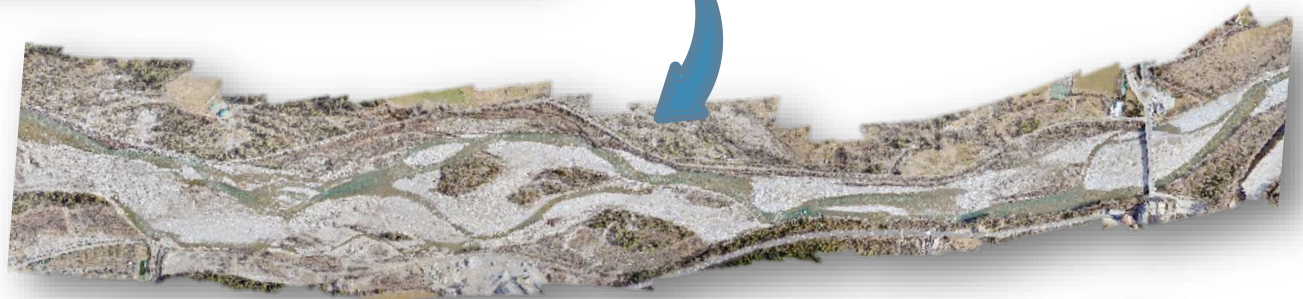
# Technology Buys us Beautiful, HR, Digital Maps...

From point clouds

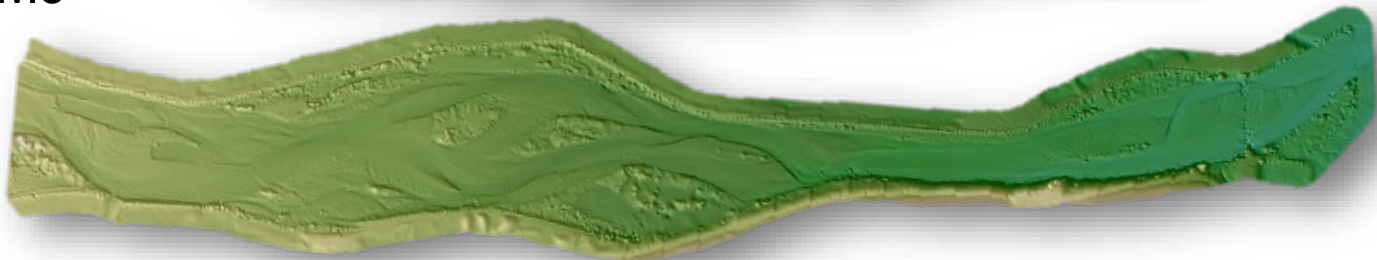


- But then what?
- What can you do with these base maps?

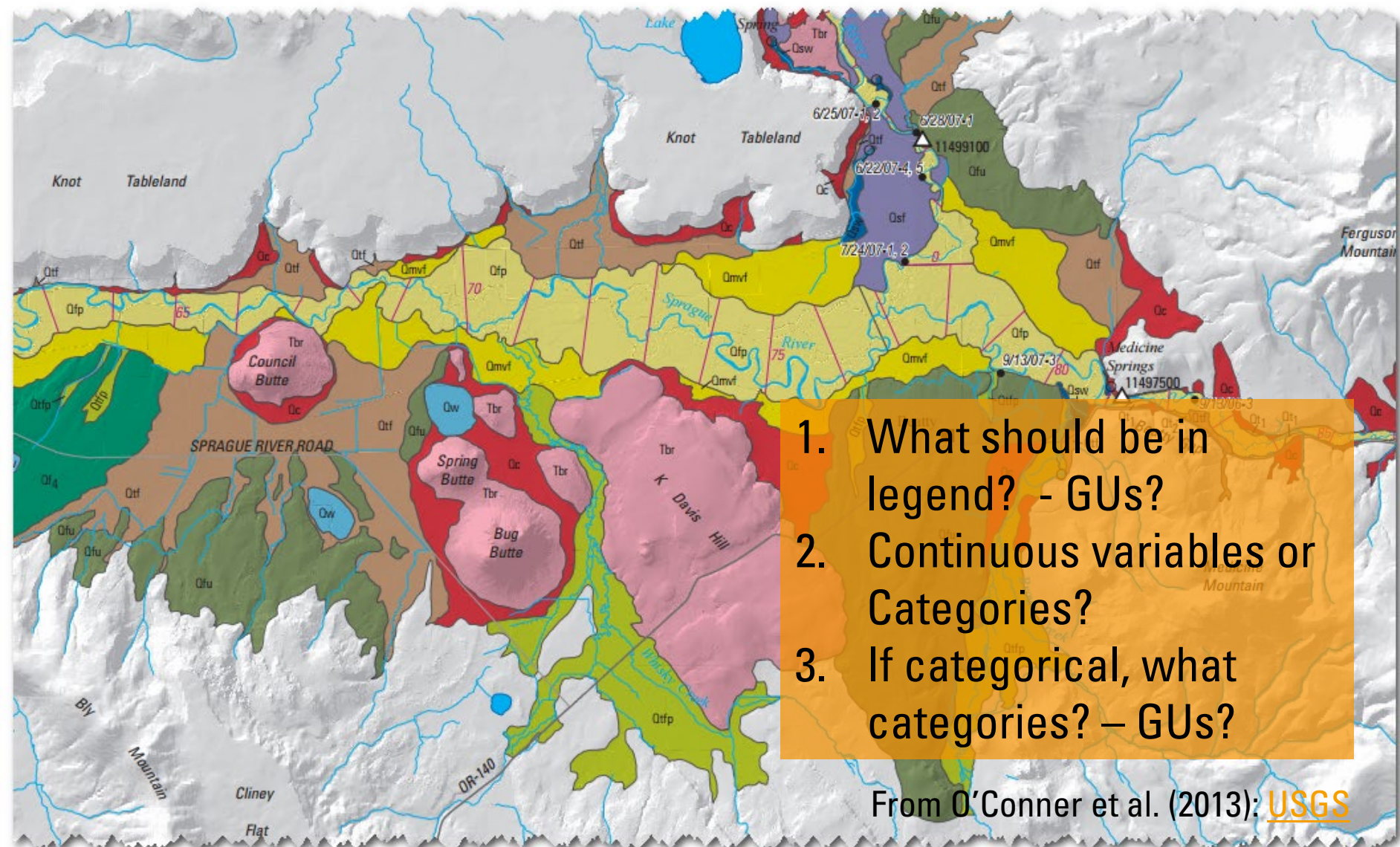
To Aerial Images



& DEMs



# What are the components of a geomorphic map?





# Instream Geomorphic Units

I. Intro → Geomorphic Units & Process-Form Associations

## II. Classification & Field Identification

III. Your Book (River Styles)

I. Sculpted, Erosional Bedrock & Boulder GUs

II. Mid-Channel, Depositional GUs

III. Bank-Attached, Depositional GUs

IV. Sculpted, Erosional Fine-Grained GUs

V. Unit & Compound GUs

VI. Forced GUs

IV. Continuum of GUs

V. Fluvial Taxonomy GUs (Topographically Defined)

I. Tier 1 – Stage

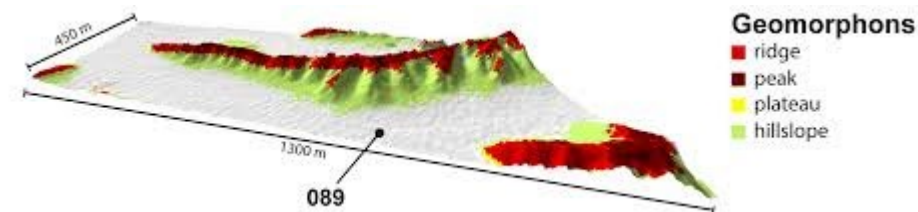
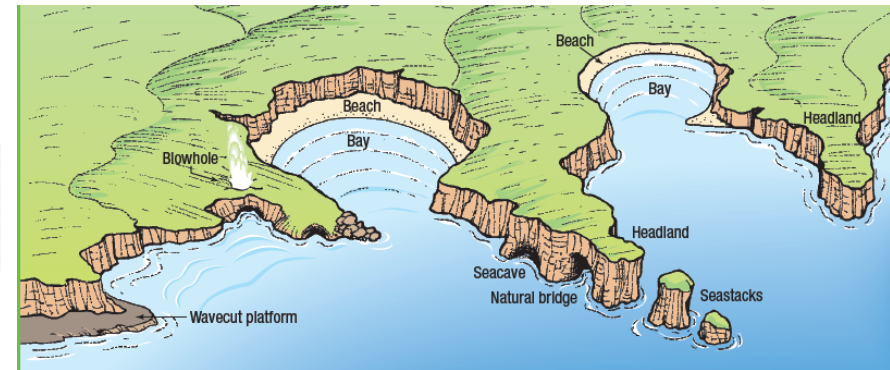
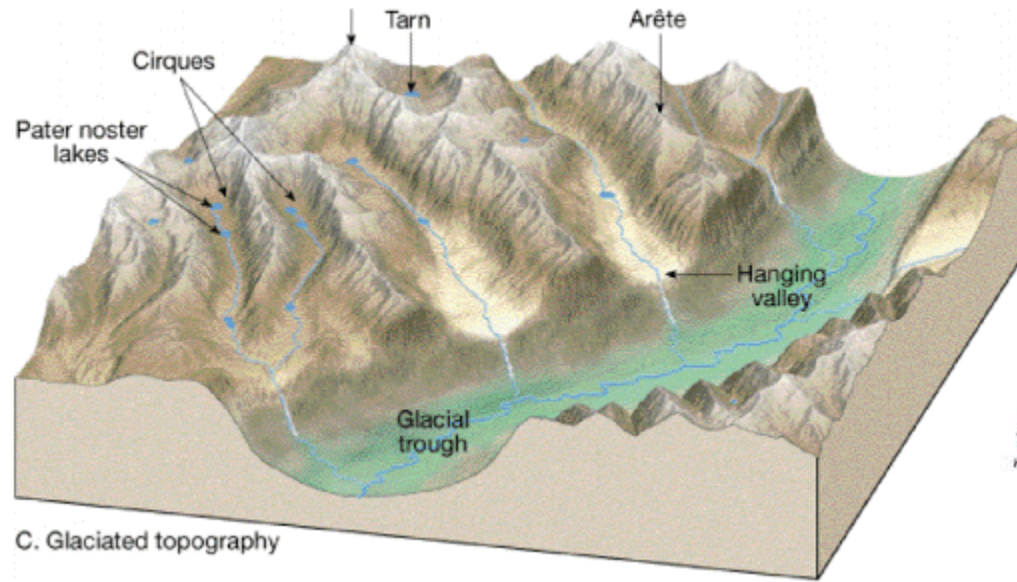
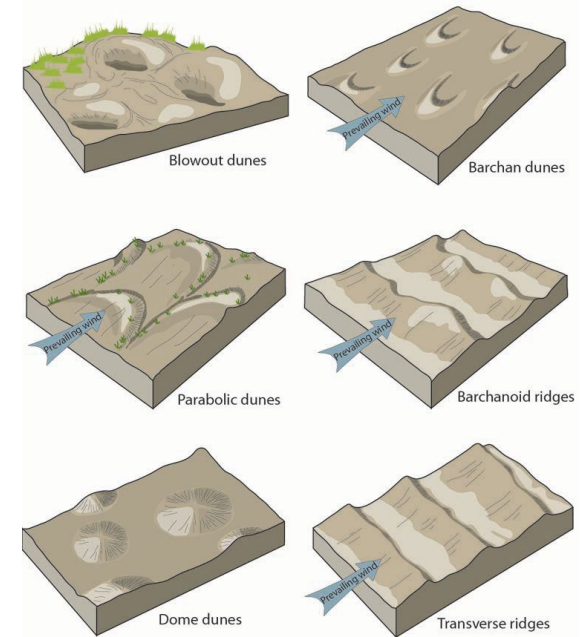
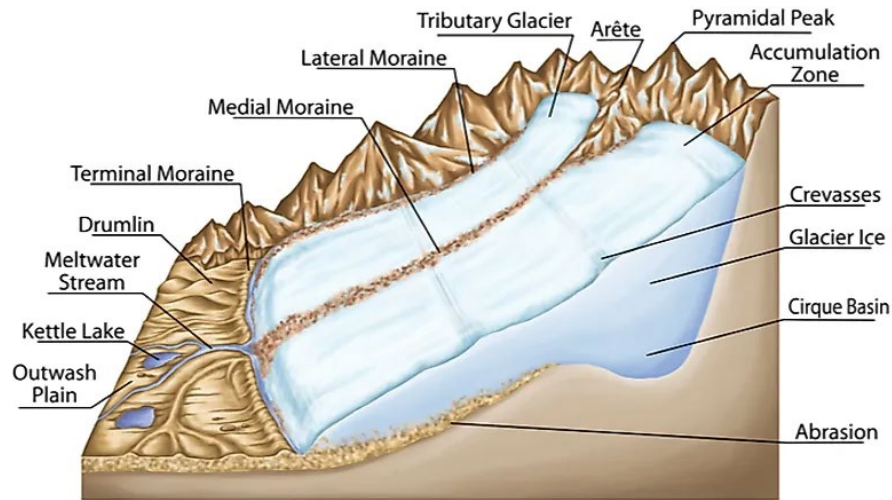
II. Tier 2 – Shape / Form

III. Tier 3 – Attributed

VI. GUT (Geomorphic Unit Toolkit)



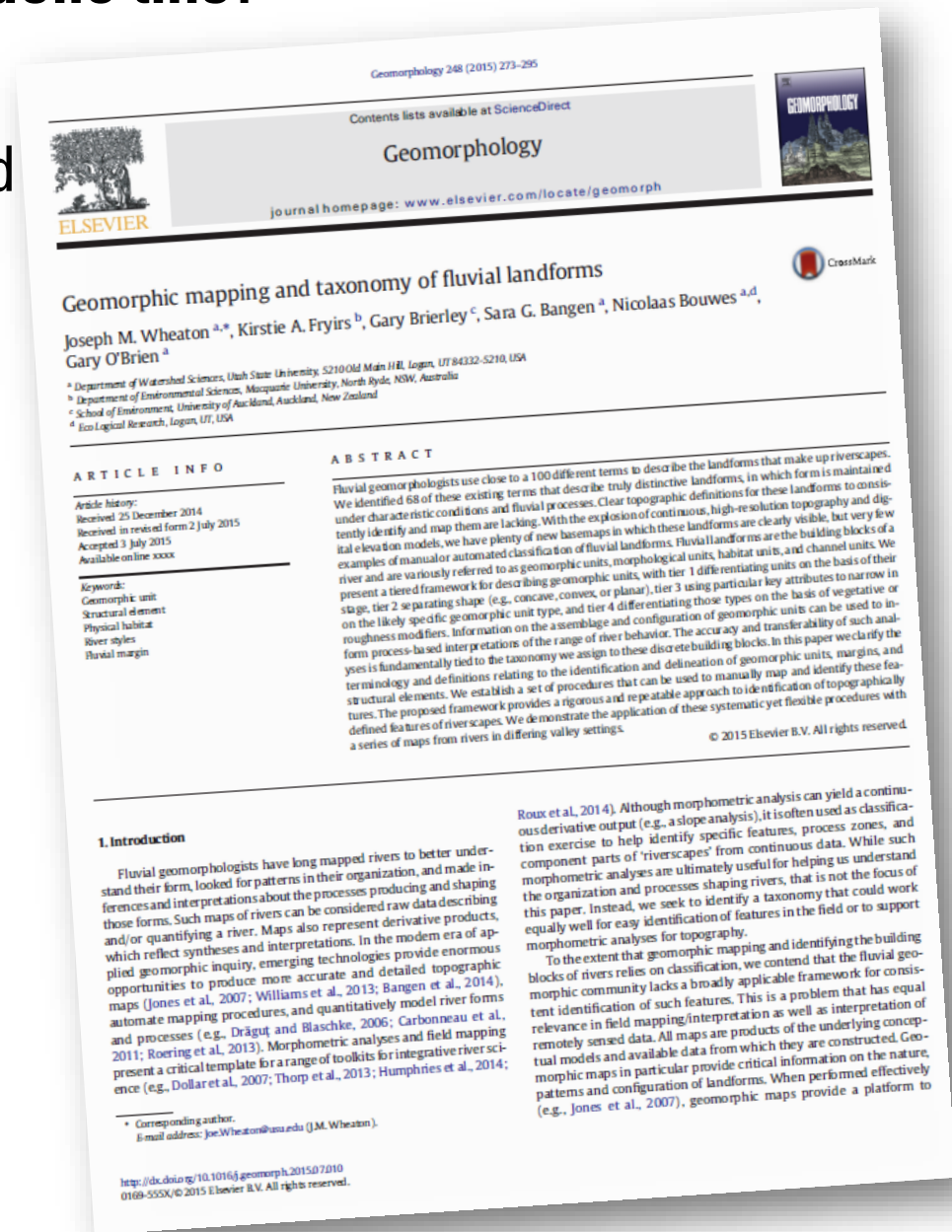
# Landforms more Consistent in other Geomorphology Sub-Disciplines



# Fluvial... not so good

## Surely, someone had already done this?

- In glacial, hillslope, coastal and aeolian geomorphology, the landforms are fairly consistently defined
- In fluvial, we found over 100 different terms to describe geomorphic units, of which 68 were actually distinctive...
- The legend should include a) margins, b) geomorphic units, and c) structural elements



# Four Primary Motivations for Better Identifying Geomorphic Units

1. Geomorphic Units are building blocks of a reach
2. Instream geomorphic Units comprise aquatic habitat -> Build stronger habitat relationships
3. Geomorphic Units are readily derivable from topography, if we have clearer topographic definitions
4. Geomorphic Unit Assemblages are predictable by reach type & condition

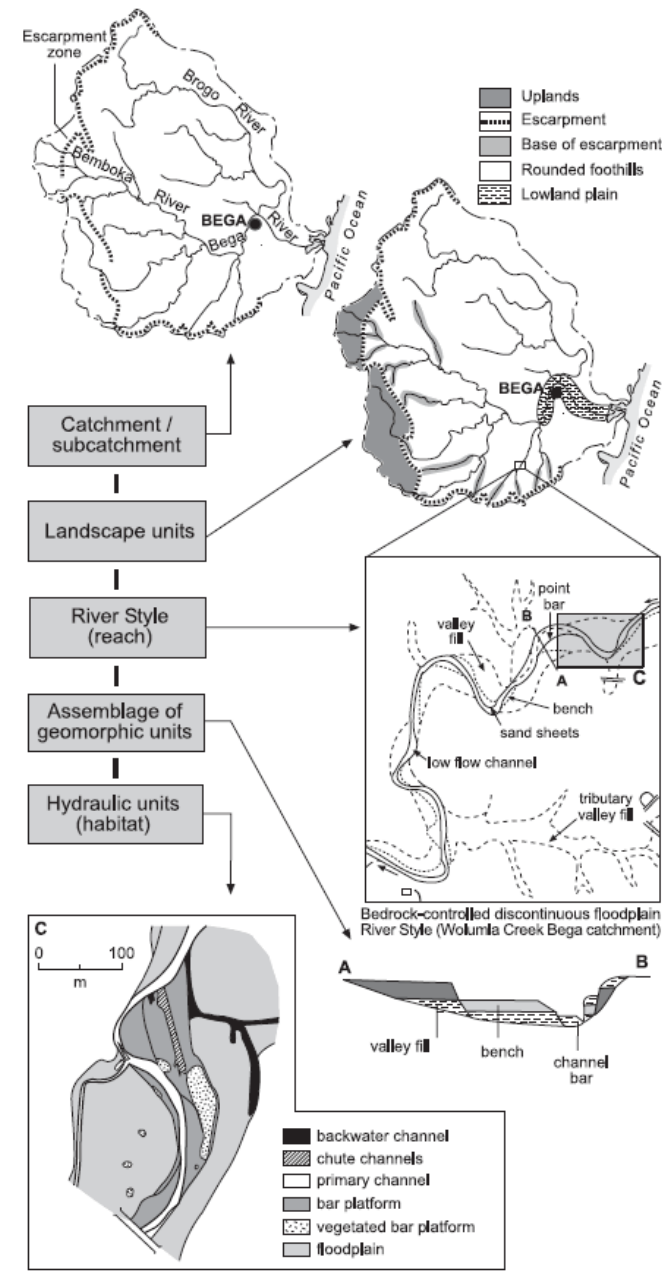


Figure from: Brierley & Fryirs (2005)



# Differentiation of GUs

- Position
- Morphology (shape & size)
- Sediment Analysis (morphostratigraphy)
- Deposition/Erosional \*

## Categories of geomorphic units and measures used to identify them in the field

Geomorphic units are initially categorised according to their **position** along a river course. *Instream* geomorphic units are found within the channel zone itself (**considered at bankfull stage**). They comprise *sculpted/erosional* (bedrock or *fine-grained*) forms, *mid-channel depositional* forms, and *bank-attached depositional* forms. *Floodplain* geomorphic units, described in Chapter 9, occur outside the channel zone and are formed and reworked at flow stages beyond bankfull when the floodplain is inundated by overbank flows.

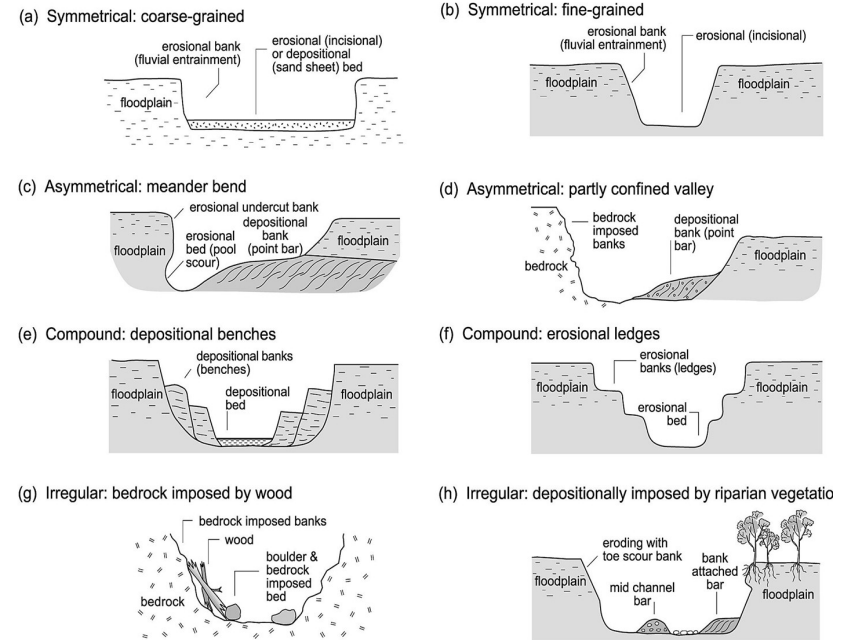
**Table 6**

Definition of key attributes for differentiating tier 3 in-channel geomorphic units; abbreviations: GU (geomorphic unit), DS (downstream).

Key Tier 3 attributes:	Types	Description
GU <b>Forcing</b>		Occurs when a non uniform hydraulic flow pattern creates a flow environment conducive to forcing the formation, maintenance or accentuation of a geomorphic unit
	└ Not forced	The GU forms on its own (e.g. free bars)
	└ By structural element	Forcing can be caused by structural elements (e.g. large woody debris causing a plunge pool or an eddy bar)
	└ By geomorphic unit	Forcing can be caused by another geomorphic unit (e.g. a pool can be forced by a bar)
	└ By planform	Forcing can be induced by sinuosity (e.g. flow separation on inside bends leading to point bars)
GU <b>orientation</b>	└ By flow width	Forcing is often associated with flow width expansion for depositional units and flow with constriction for erosional units
		The <b>orientation is defined by the longest axis of the geomorphic unit and relative to dominant flow direction.</b>
	└ Transverse	Transverse units are oriented perpendicular to the flow (e.g. <i>riffles</i> )
	└ Streamwise	Streamwise units are oriented parallel to the flow (e.g. <i>forced pools</i> are elongated in a streamwise fashion associated with the convergent flow jet)
	└ Diagonal	Diagonal units intersect the channel at an angle and flow is shunted diagonally over them at high flows.
GU <b>position</b>	└ Radial DS	Some units have lobate shapes (e.g. <i>lobate bars</i> ) which
		<b>Defines the position of the GU within the low-flow channel</b>
	└ Bank-attached	Many units are appended to the channel margins (e.g. <i>point bars</i> ); Note 'bank-attached' is common terminology in the fluvial literature even though the entire length of all channels are bound by true banks. Channel margins is a more generic term, but less common.
	└ Channel spanning	Some units are bank-attached on both sides and span the entire low flow channel (e.g. <i>riffles</i> )
	└ Mid-channel	Some units are not attached to a channel margin and occur in the center of a channel (e.g. <i>longitudinal bar</i> )
	└ Side-channel	For some mapping purposes, it is helpful to differentiate units that only occur in side and/or secondary channels

# Morphostratigraphy & Bounding Surfaces

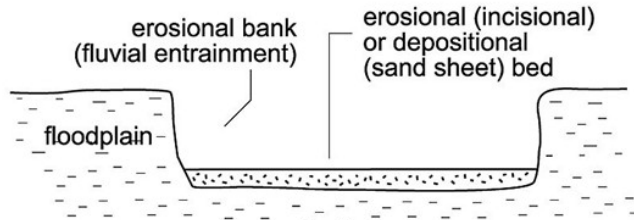
that formed the feature (Chapter 6). In most cases, geomorphic units can be identified using visual estimates of texture, differentiating the relative mix of bedrock, boulders, gravels, sands or silt/clay. More detailed assessments of river process and behaviour examine the architecture of a depositional body, interpreting the facies assemblage that makes up the geomorphic unit (i.e. its **morphostratigraphy**). Each geomorphic unit is comprised of characteristic facies assemblages. Analysis of depositional sequences can be used to interpret the flow conditions under which a geomorphic unit was formed and reworked. In many cases, geomorphic units are comprised of specific assemblages of sedimentary structures. For example, longitudinal bars are typically comprised of coarser material at the bar head (typically gravel), grading down-bar in terms of bed material texture and sedimentary structures (Sr and Sh facies) reflecting downstream growth of the bar. Gravel/sand point bars in actively migrating channels have cross-bedded sedimentary structures that dip towards the channel (facies Sp, St and Sh). Levee deposits are typically comprised of stacked sequences of sand and silt that thin away from the channel. This reflects the progressive vertical accretion of the feature during overbank flow (Sh and Fm facies). Levees typically grade to floodplain and backswamp environments that are typically comprised of Fsm or Fm facies.



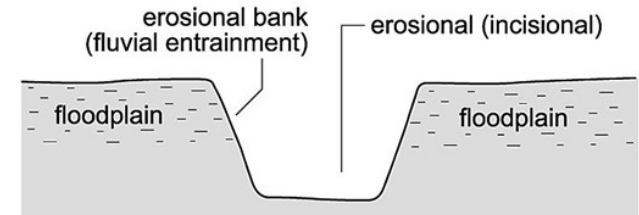
The depositional or erosional origin of geomorphic units is reflected in their **bounding surfaces** which define their geometry. Analysis of sediment exposures can be used to appraise the formation and reworking of preserved features. For example, erosional basal contacts are demarcated by distinct unconformities in sediments. The position and relative juxtaposition (spatial association and **stacking arrangement**) of surrounding geomorphic units aids interpretation of the history of primary deposition and subsequent reworking. In general terms, longitudinal bars are

# Channel Shapes

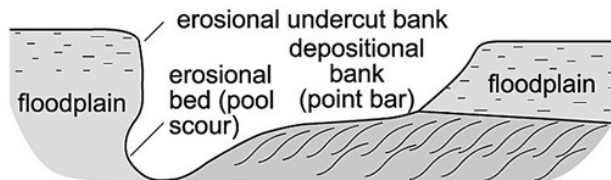
(a) Symmetrical: coarse-grained



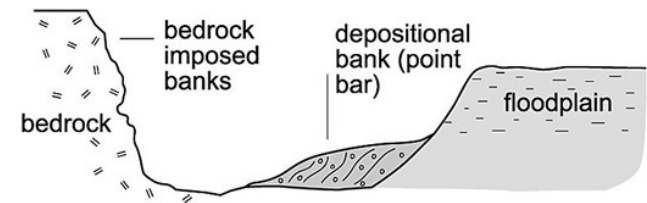
(b) Symmetrical: fine-grained



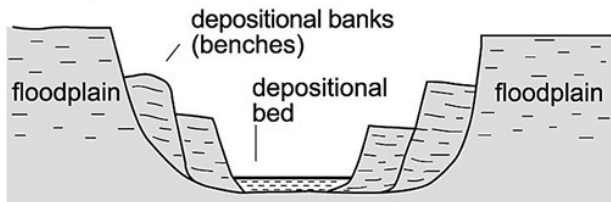
(c) Asymmetrical: meander bend



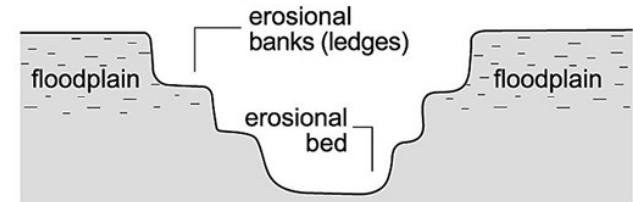
(d) Asymmetrical: partly confined valley



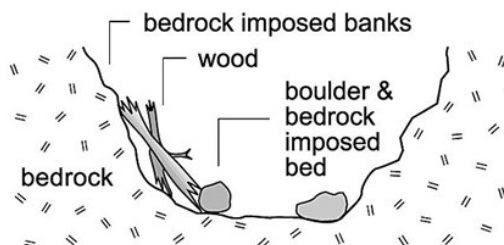
(e) Compound: depositional benches



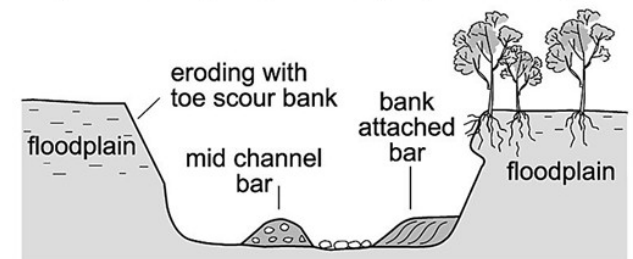
(f) Compound: erosional ledges



(g) Irregular: bedrock imposed by wood



(h) Irregular: depositionally imposed by riparian vegetation





# Instream Geomorphic Units

- I. Intro → Geomorphic Units & Process-Form Associations
- II. Classification & Field Identification
- III. Your Book (River Styles)**
  - I. Sculpted, Erosional Bedrock & Boulder GUs
  - II. Mid-Channel, Depositional GUs
  - III. Bank-Attached, Depositional GUs
  - IV. Sculpted, Erosional Fine-Grained GUs
  - V. Unit & Compound GUs
  - VI. Forced GUs
- IV. Continuum of GUs
- V. Fluvial Taxonomy GUs (Topographically Defined)
  - I. Tier 1 – Stage
  - II. Tier 2 – Shape / Form
  - III. Tier 3 – Attributed
- VI. GUT (Geomorphic Unit Toolkit)

# Process-Form Associations of Instream GUs

- Four categories differentiated:
  1. Sculpted, erosional bedrock and boulder units
  2. Mid-channel, depositional units
  3. Bank-attached, depositional units
  4. Sculpted, erosional fine-grained units