探討河階成因性名詞之必要性

何立德

摘 要

近年來岩石河階的研究發現，在絕對海水面變動影響小、構造運動持續穩定抬升的環境下，氣候變遷所造成的沈積物通量與河流流量變化，可能影響岩石河階的發育。本文收集上述環境下的全球岩石河階研究個案，歸納出三種岩石河階的發育模式。從這三種模式與岩石河階定年的資料中發現，岩石平台(strath)與岩石河階(strath terrace)有可能在冰期與間冰期交替時期，或者是在冰期中的冷暖期交替時期形成。根據這些研究的結果，我認為當岩石河階的發育可受氣候變動控制時，Bull(1990)所提出的河階分類便出現了問題，特別是Bull(1990)認為岩石河階等同於構造河階，容易使研究者在詮釋河階的成因時產生了先入為主的觀念。因此，建議在進行河階研究時，使用描述性的河階詞彙即可，至於河階的成因則依個案的情況來詮釋。

關鍵字：岩石河階、河階成因、氣候變動、地形演育
Discussion on Genetic Terminology for Fluvial Terraces

Lih-Der Ho*

Abstract

Recently evolutionary studies of strath terrace point out that in the environmental settings with minimal sea-level effects and relatively long-term steady tectonic uplifting, climatic fluctuations-controlled variations in sediment flux and river discharges could influence the formation of strath terraces. In this article I collected case studies from such an environmental background globally, and summarized three conceptual models of strath terrace formation. The models and strath terraces dating data indicate that bedrock straths or strath terraces could be formed possibly in the transitions from glacial periods to interglacial period, or from stadial to interstadial interval. According to the findings of the strath terrace studies, I question the classification of fluvial terrace proposed by Bull (1990). Especially, Bull (1990) implied that strath terrace and tectonic stream terrace are synonymous. Therefore, I suggest that it would be appropriate to simply use descriptive terminology for fluvial terrace in literatures, and interpret fluvial terrace genesis case by case.

Key Words: strath terrace, fluvial terrace genesis, climatic fluctuations, landscape evolution

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1. Introduction

In his article ‘Stream-terrace genesis: implications for soil development’, Bull (1990) proposed genetic terminology for fluvial terraces, such as tectonic, climatic, and complex-response stream terraces, to explicitly point out the causes of fluvial terraces. However, recent evolutionary studies related to fluvial terraces have shown that the classification of Bull (1990) may oversimplify the genesis of fluvial terraces, especially for strath terraces. Therefore, in this article I aim to discuss whether the genetic terminology for fluvial terraces is necessary. I first present the classification of fluvial terrace proposed by Bull (1990). Then I present recent progress in evolutionary studies related to strath terrace formation in tectonically active areas. These studies indicate that climate changes would contribute to bedrock strath development and strath terrace formations. According to the findings of the studies, I question the classification of fluvial terrace proposed by Bull (1990), especially it implies strath terrace and tectonic stream terrace are synonymous.

2. Fluvial terrace classification

A terrace is a flat surface that is limited both above and below by an inclined surface. Unconsolidated layers that result from fluvial deposition are called ‘terrace deposit’. The flat surface of a terrace is named a ‘terrace tread’ (or terrace surface), and the inclined surface a ‘terrace riser’ (or terrace scarp) (Bull, 1990). Fluvial terraces can be classified as either erosional terraces (or degradational terraces or cut terraces) or depositional terraces (or aggradational terraces or constructional terraces) (Burbank and Anderson, 2001) (Figure 1). The major difference between an erosional terrace and depositional terrace is their developing sequences. The erosional terrace is formed by lateral river erosion of the valley bottom, followed by vertical incision into the valley bed. Because the valley bottom could be bedrock or alluvium, an erosional terrace could be composed of bedrock or sediments. Therefore, an erosional terrace formed by channel incision into bedrock strath is called a ‘strath terrace’ (or ‘bedrock terrace’, or ‘rock-cut terrace’, or ‘rock-floored terrace’). Meanwhile, a depositional terrace is formed by valley-floor aggradation and subsequent stream channel incision into the alluvium. Usually, the depositional terrace is also called a ‘fill terrace’ (or a ‘filltop terrace’(Howard et al., 1968)). However, when a channel continuously incises into alluvium and forms a terrace below a fill terraces, this type of terraces is called a ‘fill-cut terrace’ (or ‘fillstrath terrace’) (Howard et al., 1968). A fill-cut terrace is a type of erosional terrace (Table 1).
Figure 1. Different terminology for fluvial terraces in the Earth Science literature. Diagram (A) from Howard et al. (1968), diagram (B) from Burbank and Anderson (2001), and diagram (C) from Bull (1990). See the text for discussion.
Table 1. Common terminology for fluvial terraces (Ahnert, 1996; Bull, 1990; Burbank and Anderson, 2001; Dury, 1970; Howard et al., 1968; Keller and Pinter, 2002; Pazzaglia et al., 1998)

<table>
<thead>
<tr>
<th>Formative process</th>
<th>Terrace formation sequence</th>
<th>Component descriptive term</th>
<th>Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erosional terrace (or degradational or cut terrace)</td>
<td>1. Vertical incision</td>
<td>Strath terrace</td>
<td>Bedrock strath mantled by a thin layer of deposits</td>
</tr>
<tr>
<td></td>
<td>2. Lateral incision and</td>
<td>Bedrock terrace</td>
<td></td>
</tr>
<tr>
<td></td>
<td>valley widening</td>
<td>Rock-cut terrace</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Vertical incision</td>
<td>Rock-floored terrace</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fill-cut terrace (fillstrath terrace)</td>
<td>Sedimentary deposits</td>
</tr>
<tr>
<td>Depositional terrace (or aggradational or constructional terrace)</td>
<td>1. Vertical incision</td>
<td>Fill terrace (filltop terrace)</td>
<td>Sedimentary deposits</td>
</tr>
<tr>
<td></td>
<td>2. Aggradation</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Vertical incision</td>
<td></td>
<td></td>
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</tbody>
</table>

Although erosional and depositional terraces are genetic terms for fluvial terraces, they do not clearly indicate what causes valley incision or aggradation. Bull (1990) proposed three distinct types of stream terraces: tectonic stream terraces, climatic stream terraces and complex-response terraces (Table 2). He explicitly stated the genesis of the fluvial terraces by applying the concepts of tectonically induced downcutting, base level of erosion, complex response, threshold of critical power, diachronous and synchronous response times, and static and dynamic equilibrium.

Table 2. Genetic terminology for fluvial terraces proposed by Bull (1990)

<table>
<thead>
<tr>
<th>Genetic term</th>
<th>Diagnostic landform</th>
<th>Spatial distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tectonic stream terrace</td>
<td>Major bedrock strath</td>
<td>Paired (distribute basin-wide)</td>
</tr>
<tr>
<td>Climatic stream terrace</td>
<td>Major aggradation surface</td>
<td>Paired (distribute basin-wide)</td>
</tr>
<tr>
<td>Complex-response terrace</td>
<td>Minor strath, fill-cut or fill terrace</td>
<td>Unpaired (limitedly distribute)</td>
</tr>
</tbody>
</table>

First, Bull (1990) said that when a river reaches and maintains dynamic equilibrium, lateral erosion of bedrock is the dominant process and may continue long enough to create bevelled surfaces beneath active channels. Such major straths represent the base level of erosion of the river, and are the fundamental tectonic terrace landform. When sea-level falls or there is local tectonic uplift, channel downcutting occurs in order to establish a new base-level of erosion, and a strath terrace is formed. The former base level of erosion is preserved as a major strath terrace whose remnants are mantled with a thin blanket of coarse bedload. However, if the strath is buried by the deposits of an aggradation event, it remains a buried feature until exposed by tectonically induced downcutting.

Bull (1990) defined a climatic terrace as one formed by climatically controlled
valley-floor aggradation and subsequent stream-channel incision into the alluvium that leaves remnants of the former active channel as the tread of a paired terrace. The tread of fill terrace is the fundamental climatic stream-terrace landform. Aggradation surfaces may be buried by subsequent episodes of deposition unless intervening tectonically induced downcutting is sufficiently that younger aggradation surfaces form below older surfaces. Finally, complex-response terraces (Bull, 1990) are formed from interactions of dependent variables, such as alluvial channels, tributary streams, valley-side slopes and divides, within a given fluvial system that has been elevated by aggradation or uplift. These unpaired, minor fill-cut, strath, or fill terraces are not easily ascribed to major tectonic processes or significant climate changes.

Bull (1990) suggested that in most cases strath terraces are tectonic and fill terraces are climatic. Bedrock strath has been suggested (Burbank and Anderson, 2001) to result from episodic tectonic uplift, in which periods of quiescence lead to strath cutting, and from climatic changes in which increased water fluxes cause lateral planation, or, alternatively, in which increased water discharge causes enhanced incision, leaving the former bed of the river as an abandoned strath; they may form irrespectively of direct climate or tectonic controls.

3. Evolutionary studies of strath terrace

Recently, several studies (Cheng et al., 2002; Formento-Trigilio et al., 2003; Hancock and Anderson, 2002; Molnar et al., 1994; Pan et al., 2003; Pazzaglia and Brandon, 2001; Wegmann and Pazzaglia, 2002) attempted to answer the following questions: Does strath terrace formation have any relation to climate changes? What controls lateral erosion and vertical incision of bedrock rivers, and how do climate changes contribute to them? Because eustatic sea-level changes are strongly influenced by global climate changes, in order to separate the effects of climate changes from sea-level changes on strath terrace formation, these studies were carried out in the interior of the Eurasian continent (Cheng et al., 2002; Molnar et al., 1994; Pan et al., 2003) or in areas where the influence of sea-level changes is minimal (Formento-Trigilio et al., 2003; Pazzaglia and Brandon, 2001; Wegmann and Pazzaglia, 2002).

Cheng et al. (2002) demonstrated how local tectonic uplifting and region base-level lowering by a normal fault has created strath terraces in Jinshaan Canyon of the Yellow River, north China, since 1.41 Ma to 5 ka. They attributed the formation of strath terraces to episodic tectonic uplifting-induced base-level lowering. In tectonically stable section of the Jinshaan Canyon, three flights of fill terraces were found and indicate valley aggradations happened when climate changed from cold periods to warm periods (197ka–96ka, 37ka–30ka, and 17ka–9ka). Their findings represent the common belief of river terraces formation (Bull,
Unlike the work of Cheng et al. (2002), other studies (Formento-Trigilio et al., 2003; Molnar et al., 1994; Pan et al., 2003; Pazzaglia and Brandon, 2001; Wegmann and Pazzaglia, 2002) first proved that tectonic uplift rates in their study sites have been constant over the long term. This inference thus eliminates the possibility of episodic uplifting-induced base-level lowering in strath terrace genesis in their study areas. However, if a river is constantly uplifted by tectonics, it should continuously incise into bedrock without forming any terrace. There must a period when the river incision rates decline and become slower than the lateral erosion rates, allowing a wide strath to be formed. What controls alternations of river vertical incision and lateral erosion in such a tectonic setting? These studies all indicate that the cause could be changes induced by climate fluctuations in river discharges and sediment supply.

Three conceptual models of strath terrace formation have been stated, based on field observations and ages of strath terraces. The first model is the river discharge-controlled model: bedrock strath developed during the last glacial period, followed by river incision because of increasing stream power during the deglacial period, and strath terraces were therefore formed (Molnar et al., 1994). The second model assumes the sediment load of a river is under its sediment-transported capacity, and sediment flux variations control strath terrace formation (Formento-Trigilio et al., 2003; Wegmann and Pazzaglia, 2002). When sediment flux increases during a warm period, when sediment load and the transport capacity are in balance, the river reaches a graded condition (Leopold and Bull, 1979; Mackin, 1948) and sediments become part of the tools that carve and create bedrock strath. Strath terraces are formed when sediment flux diminishes during a cold period, and the river returns to under-capacity condition and starts to incise into the re-exposed bedrock channel bed. The third model also considers the variations in sediment flux controlling strath terrace formation, but it assumes that the initial condition of a river is at the graded status. When sediment flux increases during a warm period, valley aggradation occurs and mantles the channel bed, preventing river incision and reinforcing channel widening. Deposition of the terrace alluvium is not related to the strath cutting. When sediment supply declines during a cold period and the river returns to the graded status, strath terraces and bedrock strath of the future terraces are cut by both vertical and lateral processes (Pan et al., 2003; Wegmann and Pazzaglia, 2002).

4. Discussion

The timing of formations of bedrock strath and strath terrace may be different from place to place, because how a drainage basin responds to climate changes may be affected by factors like climatic zone, drainage size, vegetational cover, lithology, weathering conditions
of bedrock, and a lag time of the fluvial system in responding to climate changes. Furthermore, the various conceptual models differ in interpreting the timings of the formations of bedrock strath and strath terrace (Wegmann and Pazzaglia, 2002). For example, the study by Formento-Trigilio et al. (2003) in New Zealand suggested that increase in sediment supply and floodplain development tended to happen during times of rapid environmental change, such as during a transition from glacial to deglacial periods, or a stadial to interstadial interval. In opposition to Formento-Trigilio et al. (2003), Pan et al. (2003) considered strath terraces in northwest China were abandoned during the transition from glacial to interglacial climates. Therefore, these conceptual models are location-specific and related to which climate zone the study area is in. However, both studies indicate that periods of climate transitions could contain important timings for the genesis of straths and strath terraces.

Consequently, because of the advances in geochronological methods, the ages of strath terraces, ranging widely from $10^2$ to $10^6$ years, can now be obtained, and the hypothesis of strath terrace genesis as controlled by climate changes can be tested. It is clear that climate change-induced variations in river discharges and sediment supply may overcome the influence of tectonics and control strath terrace formation. But the timings of bedrock strath carving and strath terrace formation are still unclear, and we need to accumulate more process and evolutionary studies to understand the whole picture of strath terrace genesis. Findings from the evolutionary studies discussed before ask whether it is proper to group fluvial terraces as ‘tectonic’, ‘climatic’, and ‘complex-response’ stream terraces (Bull, 1990), or treat strath and fill terraces as synonymous terms for tectonic and climatic stream terraces, respectively. Such a classification seems meaningless when strath terrace genesis could be controlled by climate fluctuations under a long-term steady tectonic uplifting. Therefore I suggest that we should simply use the descriptive terms of fluvial terraces (strath, fill, and fill-cut terrace) in the literature.

5. Conclusion

In this article I reviewed definitions of fluvial terraces, and recent progress in evolutionary studies of strath terrace genesis. Ideas of climate change-controlled variations in sediment flux and river discharges were used to interpret the genesis of strath terraces (Hancock and Anderson, 2002). Three conceptual models were established and supported by geochronological data. Strath terrace studies from New Zealand, northwest China, and North America implied that bedrock straths and strath terraces were possibly formed in the transition from a glacial to an interglacial period. Based on recent studies of strath terrace formation, I questioned the genetic terms of fluvial terraces proposed by Bull (1990) and suggested the use of descriptive terms for fluvial terraces in the literature, since the
interpretations of fluvial terrace genesis will change when knowledge of river erosion processes and dating methods are improved.

Lastly, I echo the proposals of Wohl (2000) and Whipple (2004) that more field observations and measurements are needed to understand short-term processes in mountain rivers and their influences to long-term landscape evolutions in different environmental settings. From short-term direct measurements we have noticed that different frequency and magnitude of floods (Hartshorn et al., 2002), combing with sediment supply fluctuations and grain size (Sklar and Dietrich, 1998; Sklar and Dietrich, 2001), could help to widen valley wall and incise into bedrock channel bed. However, only few numerical studies attempt to explore how variations in hydrology and sediment supply effect strath terrace formation (Hancock and Anderson, 2002; Poisson and Avouac, 2004), and only one with field data to calibrate their model (Poisson and Avouac, 2004). Therefore, I suggest that linking the studies of palaeoflood hydrology (Saint-Laurent, 2004) with strath terrace formation is a direction to study how hydrological changes in the past contribute to sediment delivery from upstream area, and valley incision and widening.

Reference


