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Surface Processes Seminar
Spring, 2002

# Annotated Bibliography-Fluvial Terraces

Bull, William B., 1990, **Stream-Terrace Genesis: implications for soil development**, Geomorphology, V.3, p.351-367.

'Stream terrace treads are landforms with temporal significance that document important transitions in types or rates of fluvial process…and represent departure from equilibrium conditions in fluvial systems.' Bull divides terraces into three general categories for the purposes of this review (a-typical terrace formation is left out for simplicities sake). Climatically or tectonically controlled terrace formation result in *major* terraces while complex-response terraces are termed *minor* terraces and represent internal adjustments within a fluvial system. Concepts such as tectonically induced downcutting, base level or erosion, complex response, threshold of critical power, diachronous and synchronous response times and static and dynamic equilibrium are employed to help understand what controls terrace formation. Bull's intent is to provide diagnostic criteria for field identification of the three fundamental classes of terraces.

This paper offers a thorough review of the basic kinds of terraces, terrace stratigraphy, what terraces represent and/or what causes terrace formation and, what concepts are typically employed when researchers try to study them. Over time, soils form within the materials that alluvial terraces are composed of given that they are preserved high enough above the modern channel such that they have not been affected by aggradational events following their initial formation. It is important for soil scientists to understand what kind of terrace the soil they are studying has formed within. The paper contains very little data and tends to raise more questions concerning terrace formation than it answers.

Engel, Scott A., Gardner, Thomas W. & Ciolkosz, Edward J., 1996, **Quaternary soil chronosequences on terraces of the Susquehanna River, PA**, Geomorphology, v.17, p.273-294

The Quaternary is best represented in the middle Atlantic region by geomorphic features preserved within SE flowing fluvial systems draining the App. Mtns. Terraces along sus. have developed in response to (1) isostasy from continental denudation and sediment loading of the continental shelf, (2) climatic fluctuations associated with glaciation and, (3) eustatic sea level changes. These terraces were used to establish time lines by generation soil chronosequences at two locations along the Susquehanna river between the Lower Piedmont and the edge of the Appalachian Plateau (150 km). **Marietta**, in the Lower Piedmont preserves seven terrace levels (QTg and Qt1-Qt6) ranging in age from modern (<150 ybp) to Early Pleistocene through Late Pliocene ( 770 ka to 2400 ka). **Mucny**, near the glacial border on the boundary between the Valley and Ridge province and the Appalachian Plateau, preserves approx. 8 terrace levels, ranging in age from modern (<150 ybp) to Middle Middle through Early Middle Pleistocene ( 300 ka to 770 ka). Soil characteristics such as (refer to article) were used to develop the soil chronosequences. Terrace age constraints are based on soil development, correlation to regional glacial stratigraphy, correlation to dated fluvial depoits and glaciofluvial deposits, terrace elevation and by paleomagnetic analysis of sediments. (Brunhes/Matuyama paleomagnetic boundary (770 ka to 2400 ka)). These correlations and ages establish time lines along the largest drainage through the Appalachian Mountains. These findings will assist in achieving a better understanding of the interaction between glaciation, fluvial processes, and eustasy for the eastern US.

Overall a good paper. Couldn't follow a lot of the soil jargon etc., but the major conclusions, ages and correlations are helpful for understanding the nature of this kind of study as well as the Susquehanna river fluvial system. The ages posed for specific terraces and correlations between the sites will be useful to compare against when I start gathering cosmogenic data and ages for myself…particularly at Marietta which I think will be more useful than Muncy. Holtwood will be interesting because no one has tried to correlate between it and these other locations.

Gardner, Thomas W., 1983, **Experimental study of knickpoint and longitudinal profile evolution in cohesive, homogenous material**, Geological Society of America Bulletin, v.94, p.664-672.

Gardner's paper summarizes the findings of a flume study conducted in 'resistant homogenous bedrock' covered by a thin veneer of alluvium. The study provides data on both short-term knickpoint evolution and long-term longitudinal-profile evolution within intermittently uplifted regions (fluvial systems which experience intermittent drops in base-level). Knickpoint evolution can be characterized by three general models: parallel retreat, replacement and inclination. These models are base on the following criteria: 1) relationship between bottom shear stress and critical shear stress needed to initiate motion of bedload, 2) nature of the bed-lad transport discontinuities (?) and, 3) spatial variability of bedrock resistance to fluvial erosion. It is concluded that parallel knickpoint retreat does not occur in homogenous bedrock except in those cases where erosion is influenced by extension bedrock jointing (like the Wissahickon Schist in the High Piedmont of the Susquehanna River). Instead, the original vertical (or nearly vertical) knickpoint is replaced near its place of origin by two morphologically distinct reaches: 1) a k.p. face that decreases in slope while slowly migrating headward and 2) an incising reach above the knickpoint lip that increases in slope while rapidly migrating headward (refer to text and Fig. 13).

Interesting paper if you are at all interested in knickpoint initiation and migration and longitudinal profile development within fluvial systems. I am never quite sure how applicable these idealistic experimental studies are to real world, but it all seems to make sense. Gardner's writing is clear and readable if you are familiar with the geomorphology jargon.

Mills, Hugh H., 2000, **Apparent increasing rates of stream incision in the eastern United States during the late Cenozoic**, Geology, v.28, n.10, p.955-957.

This is a review paper (no primary data) in which Hugh synthesizes data from 16 previous studies in an effort to argue for an increased rate of stream incision during the late Cenozoic. A log-log regression of age and height above modern river channels of terraces or stream associated cave levels (?) show that vertical spacing between paleoriver (terrace) levels decreases with increasing age, suggesting an increased rate of incision in recent times. Hugh argues that this increase may reflect the long-term cooling and lowering of sea level that have taken place since the late Miocene. In contrast, the results of this comparison may be the result of 'an inherent effect of measured time interval on process rate' as described by Gardner et al., 1987. In his 1987 paper, Gardner showed that geologic process rates tend to decrease for increasing measurement intervals (longer time span).

Honestly, I don't believe Hugh's theory. I believe there are far too many other variables at stake here…i.e.- what are or have the rivers been incising into (alluvium vs. bedrock) and has it always been the same 'stuff.' Most dating methods employed in terrace studies are relative methods that, at best, offer a substantial age range that is difficult to accept or refute. Terrace studies on the Susquehanna river (which Hugh uses in this argument) display flexural upwarping which completely negates any conclusions you can drawn from age vs. height relationships.

Pazzaglia, Frank J. & Gardner, Thomas W., 1993, **Fluvial Terraces of the Susquehanna River,** Geomorphology, v.8, p.83-113

Fluvial terraces preserved along the lower reaches of the Susquehanna record the late-stage geologic and geomorphic evolution of the US Atlantic Passive Margin. The Susquehanna river originated with the opening of the Atlantic ocean during the Jurassic or Cretaceous (100-180 mya). Terrace ages are established with downstream correlation to dated coastal plain and fall zone fluvial deposits, relative weathering and soil profile characteristics. Terrace age and long. profile suggest complex interactions among relative base level, long-term flexural isostatic processes, climate and river grade. Their model poses that 'straths are continually cut' during periods of relative base level stability (slow, steady, isostatic continental uplift acting 'in concert' with eustatic rise). A change in the system (sea level drop or climate change etc.) initiates the formation of a knickpoint which migrates up stream as the river adjusts to the new base level. Strath terraces in the lower Susquehanna gorge probably reflect modulating factors other than base level changes (such as climate etc.) because the relatively 'high frequency' fluctuation of Pleistocene eustasy (?) did not afford the river enough time to attain a new graded profile. [(p.104) confusing] In the sus. fluvial system, relative base level does not reflect eustatic sea level, but a complex interaction between eustacy and passive margin isostacy. Terrace profile deformation is thought to be the result of cumulative flexural upwarping of the Atlantic margin. Flexural isostacy is suggested as a first-order, regional deformation mechanism. Central Appalachian Piedmont has risen app 90 m or (6m/my) since the middle Miocene. In contrast Holtwood, 'driven by both flexural isostacy and eustatic drawdown,' has risen app. 150m or (15m/my).

This is a rather dense paper. It is very good if you are interested in geomorphic features of the Susquehanna River itself, or in an example of a classic geomorphological study. There is a very good summary and explanation and diagrams of terrace genesis, effects of relative base level change, and effects of flexural isostacy on p. 103-105.

Pazzaglia, F. & Gardner, T. W., 1994**, Terraces, Fluvial Evolution, and Uplift of the Lower Susquehanna River Basin**, in: Various aspects of Piedmont Geology in Lancaster and Chester Counties, Pennsylvania, 59th Annual Field Conference of Pennsylvania Geologist.

This paper is a chapter from a guidebook covering the 59th annual field conference of PA geologists. It offers a good review of what Frank Pazzaglia explains in depth in the 1993 paper (which resulted from his PhD work with Thomas Gardner at Penn State). As well, this chapter gives specifics of terrace lithology, coastal deposit correlations, material source, etc. Good figures of terrace longitudinal profiles and regional correlation (fig 51). Good discussion of terrace genesis in relation to equilibrium state as opposed to incision cause by ‘modulating external factors.’ Discussion of effects of Flexural Isostacy and the Geodynamic Model**.**

This is a comprehensive review of most correlation and dating of geomorphic features and deposits that had been done up to 1994 within the Susquehanna basin. It also tries to pull together some thoughts and theories regarding passive margin evolution and flexural isostacy caused by sediment loading in the Salisbury embayment which he discusses in much more depth in other 1994 paper (late Cenozoic flexural deformation of the US Atlantic margin). It is much easier to follow than most of franks other papers because it was written for people attending the conference, not necessarily geomorph. buffs who read his other ‘Journal of Geophysical Research papers).

Zaprowski, Brent J., Evenson, Edward B., Pazzaglia, Frank J. & Epstein, Jack B., 2001, **Knickzone propagation in the Black Hills and northern High Plains: A different perspective on the late Cenozoic exhumation of the Laramide Rocky Mountains**, Geology, v.29, no.6, p.547-550.

Zaprowski etal. propose knickpoint migration caused by base-level falls as a mechanism for the late Cenozoic incision and exhumation (unroofing) of the Black Hills and northern High Plains, South Dakota. As a result, they argue that knickpoint migration, as opposed to epeirogenic uplift and or climate change, must be entertained as a viable mechanism for the ultimate exhumation of the Laramide Rockies during the late Cenozoic. As knickzones propagate upstream from the Missouri River in response to the presumed base-level fall, paired terrace treads are left behind. Tread relief, strath relief, grain size and relative pedogenesis are used to identify four levels of terraces in the Black Hills and surrounding High Plains below knickzones. The genetic relationship between the knickzones and terraces is strongly indicative of features propagating upstream in response to ‘some unspecific base-level fall.’

This paper is a quick read discussing the application of the study of geomorphic features (such as terraces and knickzones) to attempt to unravel late Cenozoic landscape evolution. It is especially interesting in that it harps back to the Molnar and England, 1990 (Chicken, or egg?) paper that we read at the beginning of seminar.

**More fluvial terrace papers (un-summarized):**


Pazzaglia, Frank J. & Gardner, Thomas W., 1994, **Late Cenozoic flexural deformation of the middle US Atlantic Margin**, Journal of Geophysical Research, v.99, n.B6, p. 12,143-12,157.

Pazzaglia, Frank J., Gardner, Thomas W. & Merritts, Dorothy J., 1998, **Bedrock Fluvial Incision and Longitudinal Profile Development Over Geologic Time Scales Determined by Fluvial Terraces**, in *Rivers Over Rock*, edited by Keith J. Tinkler & Ellen E. Wohl, American Geophysical Union, Washington DC, 1998.


**Fluvial terrace and cosmogenic isotope papers:**


Burbank, Douglas W., Leland, John, Fielding, Eric, Anderson, Robert S., Brozovic, Nicholas, Reid, Mary R. & Duncan, Christopher, 1996, **Bedrock Incision, Rock uplift and threshold hillslopes in the northwestern Hmalayas**, Nature, v.379, p.505-510

Hancock, Gregory S., Anderson, Robert S., Chadwick, Oliver A. & Finkel, Robert C., 1999, **Dating fluvial terraces with 10Be and 26Al profiles: application to the Wind River, Wyoming**, Geomorphology, v.27, p.41-60.

Perg, L.A., Anderson, R.S. & Finkel, R.C., 2001, **Use of a new 10Be and 26Al inventory method to date marine terraces, Santa Cruz, California, USA,** Geology, v.29, no.10, p.879-882

Repka, James L., Anderson, Robert S. & Finkel, Robert C., 1997, **Cosmogenic dating of fluvial terraces, Fremont River, Utah**, Earth and Planetary Science Letters, v.152, p.59-73.