Geomorphic Evolution in a Volcanically Disturbed River System—Relative Significance of Vertical Versus Lateral Adjustments

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A 2.5-km^3 landslide and subsequent pyroclastic flows during the 1980 eruption of Mount St. Helens buried upper North Fork Toutle River (NFTR) valley. Since then, a new drainage network has evolved. A suite of cross-sectional surveys over nearly 40 years at 16 locations along a 20-km reach of river valley documents channel evolution. We analyze spatial and temporal changes in channel evolution using two new metrics: (1) a shape index that defines the degree of U-shaped or V-shaped valley geometry (Figure 1); and (2) an alluvial phase-space diagram (Figure 2) that relates bed degradation or aggradation to increases or decreases in cross-sectional area. The proposed phase-space diagram builds on a channel-stability diagram (Watson et al. 2002) and a geomorphic covariance diagram (Brown and Pasternack 2017). A key advance in our phase-space diagram is delineation of a nine 'phase-space domains' that represent different styles and stages of morphological evolution. For example, one domain (diagonal line in Figure 2) represents uniform aggradation or degradation across the width of an initial reference channel—that is, changes in bed elevation that mimic piston-like upward or downward motion. Channel changes in most domains, however, are dominated by impacts of lateral morphological adjustments. Identification of these 'phase-space domains' supports deeper insights concerning geomorphic processes responsible for long-term channel evolution.

Unlike a linear-response model described by Meyer and Martinson (1989), our analysis reveals channel development has been distinctly nonlinear and non-sequential. Rather than following a linear and sequential trajectory of (1) channel initiation and incision, (2) aggradation and widening, and (3) episodic scour and fill with little change in bed elevation, long-term channel evolution has been more complex with vertical and lateral adjustments intertwined throughout. Phase-space diagrams for cross sections along upper NFTR channel (e.g., Figure 3) show that (1) channel evolution has followed a complex trajectory that has migrated through several phase-space domains non-sequentially, featuring (i) degradation with both widening and narrowing, (ii) aggradation with both widening and narrowing, (iii) bed fluctuations with little change in cross-section area, and (iv) changes in cross-section area with little change of bed elevation; and that (2) lateral adjustments became predominant after the late 1980s to mid-1990s when vertical bed adjustments largely diminished and the channel long profile largely stabilized (Zheng et al. 2014). Documented nonlinearity in long-term evolution of upper North Fork Toutle River channel is consistent with a stream-evolution model proposed by Cluer and Thorne (2014) (see also Zheng et al. 2017). Persistent channel and valley widening, and reworking of the channel bed, are responsible for maintaining sediment delivery from this basin at levels elevated relative to pre-eruption conditions. Elevated sediment loads will likely persist until the valleyfloor width greatly exceeds the active channel-migration zone, and/or channel slopes and valley walls stabilize.

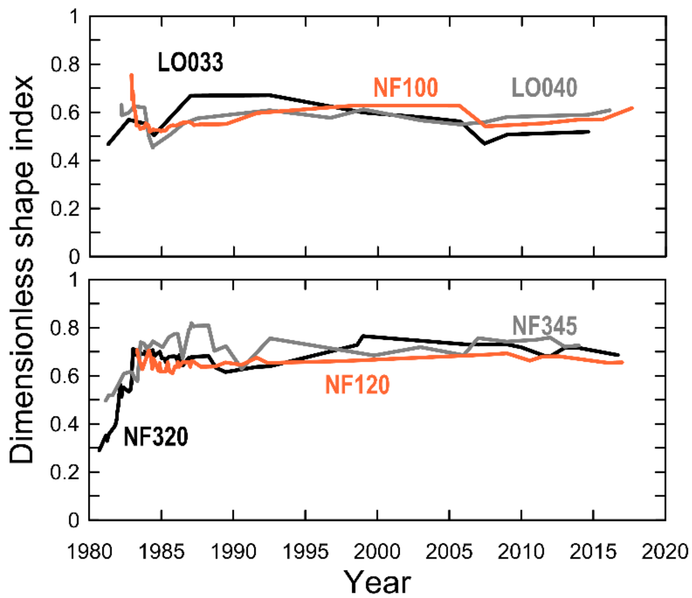

Figure 1. Examples of temporal trends in cross-sectional shape indices derived from cross-section profiles in erosional (top graph) and transitional (bottom graph) domains in upper North Fork Toutle River. The shape index is defined as the area of a cross section relative to a hypothetical rectangular area eroded uniformly across the section top width to the channel-thalweg elevation. Highly entrenched geometries (quasi-V-shaped) have shape indices ~≤0.5. Sections having more U-shaped or box-like geometries have indices >0.5.

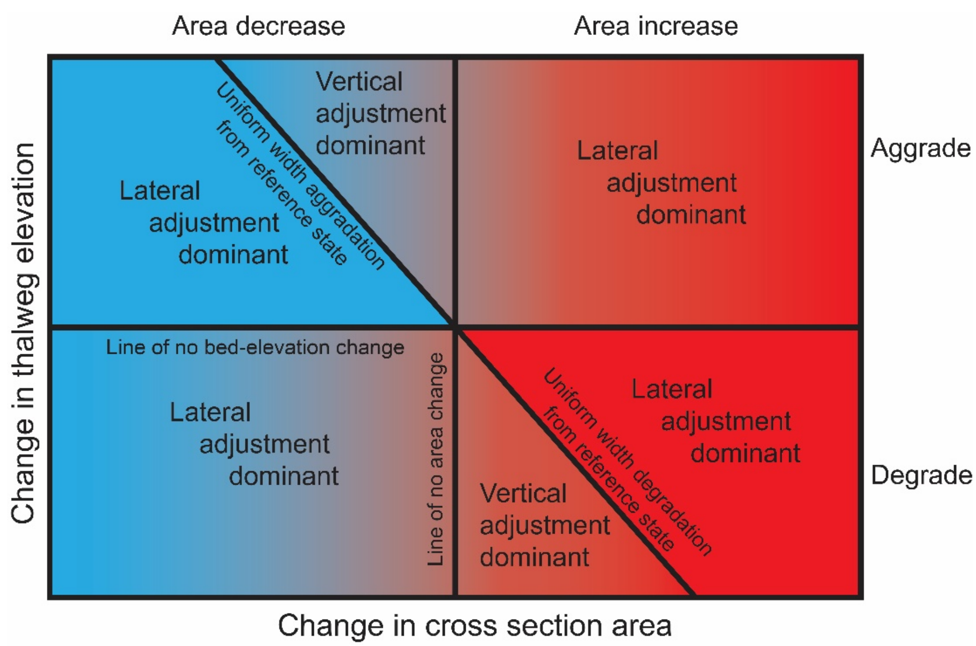

Figure 2. Alluvial phase-space diagram illustrating relations between vertical and lateral adjustments and changes in cross-sectional area. Nine 'phase-space domains' (3 lines, 6 regions) depict varying dominance of vertical (degradation or aggradation) and lateral (widening by erosion, narrowing by deposition or erosional entrenchment) adjustments. Color gradients illustrate gradual changes in process dominance between phase-space domains.

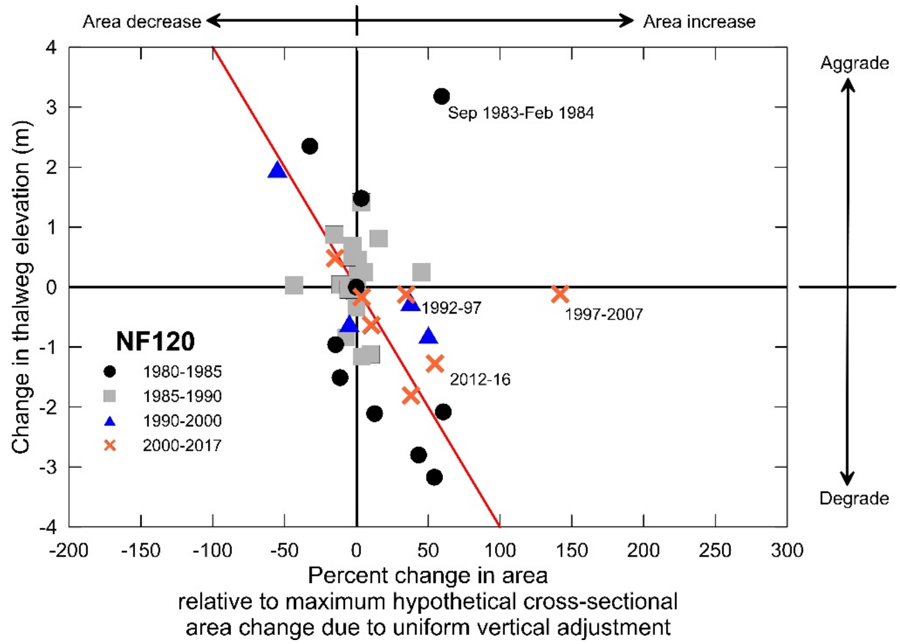

Figure 3. Example alluvial phase-space diagram for North Fork Toutle River cross-section NF120. Diagram depicts relations between change in bed elevation and percent change of cross-sectional area relative to a maximum hypothetical change of area under constant-width aggradation or degradation from an initial reference state. Red diagonal line represents a hypothetical linear relation between changes in bed elevation and cross-section area under uniform-width conditions. Data reflect changes between consecutive surveys and are categorized by time after the 1980 eruption. Times elapsed between selected surveys are highlighted.

References

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