2013 Bretz Club Field trip Guide, Part Deux: ***Kentucky Falls extravaganza***

Saltate, meander, and plummet: Sediment pathways in the Oregon Coast Range

Saturday, 27 April 2013 **Led by Josh Roering, Jill Marshall, Kristin Sweeney, Unviersity of Oregon**

Notes: The field trip entails a 4-mile round-trip hike. Bag lunches will be provided by OIMB for Bretz registrants. We'll make several stops along the way and then break for lunch at the base of Lower Kentucky/North Fork Smith River Falls. After lunch there will be one or two more stops. If you need to leave early to get home, feel free to head up the trail to your car at any time. We'll provide a handout with directions for getting from the parking lot to Hwy 126, which is the shortest route for most people to get home. Otherwise, please ask of questions and be safe in this beautiful spot!

Stops and themes for discussion

1. Parking lot: General site background and logistical discussion.
2. Mid-way b/w parking lot and Upper Kentucky Falls:
    a. Note and discuss: tree throw pit/mound features.
    b. Small-order catchment dynamics: colluvial infilling and excavation by debris flows
3. Base of Upper Kentucky Falls:
    a. Petrology of Oligocene intrusions
    b. Incision and retreat of knickpoints
    c. Physical and chemical alteration of bedrock
    d. Baselevel controls in the Oregon Coast Range
4. Wooden Bridge over Kentucky Creek
    a. Sediment transport and suspended sediment concentration vs. discharge relationships in a threshold-dominated landscape.
5. Downstream of bridge
    a. Gargantuan Tree throw pit/mound
    b. Discuss role of bioturbation in soil production
6. Base of Lower Kentucky Falls/North Fork Smith River Falls
    a. LUNCH STOP
    b. Discuss waterfall retreat and landscape adjustment in the upstream watershed
7. Return upstream: Historic bridge remains and logging camp
    a. Intrepid path (traverse to top of falls and upstream to historic bridge remains)
        i. Requires steep hillside slog and shallow stream walking
    b. Standard path
        i. Back up trail to wooden bridge and wait there for a bit of gentle bushwhacking
    c. Discuss
        i. Logging and legacy of land-use practices, in-stream structures
        ii. Landscape evolution and adjustment upstream of knickpoint
            1. Hillslope soils
            2. Valley width
8. Return to vehicles and head home…drive safely!

A Brief Summary of Oregon Coast Range Geology, Geomorphology, Tectonics, and Climate

Spanning 200 miles along the Pacific, the Oregon Coast Range is defined by a 30-40 mile wide swath of moderately high mountains. The range averages 1,500 feet in elevation and has a maximum elevation of 4,097 feet at Mary's Peak. Slopes and drainage basins are consistently steep through the range, approaching 50° in many localities. Pacific storms buffet the range in the wet, winter months and support thick forests of Douglas fir and hardwood species. The average annual rainfall in the range is over 100 inches per year. Several rivers flow west across the Oregon Coast Range and empty into the Pacific. These rivers generally flow across sedimentary or volcanic bedrock and do not have significant storage of sediment in river bars or banks. Once home to an abundance of trout, salmon, and other fish, rivers and streams in the Coast Range now harbor a small fraction of the original aquatic population.

The Oregon Coast Range is a belt of uplifted land lying along the Pacific Coast of Oregon. The uplift is a result of plate convergence. About 400 km west of the Coast Range lies the spreading center, which separates the Pacific plate (which extends to just east of Japan) and the Juan de Fuca plate, which descends under the North American Plate along the Cascadia subduction zone. The Coast Range overlies the subducted Juan de Fuca plate and the lies about 150 to 200 km to the east of the Cascadia subduction zone. The region seaward of the location of volcanism is referred to as the "forearc" and that the materials found in the forearc are comprised of rocks scraped off the descending the subducting slab ("accretionary wedge") and of rocks deposited within the basins ("forearc basins") created by deformation of the accretionary wedge.

The Oregon Coast Range is composed of accreted oceanic sediments. The oldest rocks, the Siletz River volcanics, are oceanic crust formed during the Paleocene to middle Eocene (about 60 to 45 million years ago). Deposited synchronously with these volcanics but also overlying them and intruded by them is a regionally extensive marine sandstone and siltstone. Commonly referred to as the Tyee formation this unit is mostly formed by repeated deposition of dense currents of sediment (turbidity currents) derived from uplifted terrestrial sources. Our study sites lie entirely within this unit. Successively younger deposits of sediments and volcanics are found to the east of the coast range and along the coast. Overall the rocks are gently folded and have a slight westward dip (Kelsey et al., 1996).

During the Oligocene (-25 million years ago), uplift of sedimentary basins in Oregon resulted in the westward migration of the coastline from as far east as Idaho towards the present position. Synchronous with uplift, giant fissures in northern Oregon brought lava flows up from the subducting plate. Dikes and sills also intruded into the Eocene and Miocene sedimentary rocks that make-up most of the Coast Range today. These isolated volcanics tend to resist weathering and erosion more than the surrounding sedimentary rocks and constitute some of the prominent peaks in the Coast Range. Continued uplift of the coast has led to the development of marine terraces along the Oregon coast. These features record the history of sea level change and uplift, and specifically they record differential uplift along the coast that may result from faulting.

The Juan de Fuca plate is being subducted at about 4 cm/yr (De Mets, et al., 1990). It dips beneath the Coast Range at about 13 to 16 degrees (Trehu et al., 1994). One of the most peculiar and troubling aspects of the Coast Range is the low seismicity of the region in recorded time. Concerns about potential seismicity associated with the Cascadia subduction zone has prompted many researchers to search for evidence of historical earthquakes in the region (e.g. Atwater, 1987). Deformation of local coastal marshes and Quaternary terraces has been interpreted as a response to pre-historic earthquakes. Geological evidence now suggests that instead of frequent lower magnitude events the Coast Range occasionally experiences very high magnitude earthquakes (order 9.0), the most recent perhaps having occurred 300 years ago (Verdonck et al., 1995). One question we will consider is whether these rare, but very large magnitude earthquakes leave a geomorphic imprint on the landscape.

Studies of fluvial strath terraces (Personius, 1995) and marine terraces (Kelsey et al., 1996) have been used to examine the spatial and temporal pattern of Quaternary rock uplift of the Coast Range. Inerred patterns of stream incision rates appear to roughly balance rock uplift rates, i.e. the rivers keep pace with uplift during the late Quaternary. A complex pattern is suggested, with generally more rapid incision in the north. Resurveys of targets and analysis of tide gauge records during the past 50 years enables an estimate of contemporary vertical deformation. These rates are in the south as much as 10 times higher than late Quaternary rates inferred from stream incision rates. As Mitchell et al. (1994) argue these data, which represent a period of little seismicity record significant strain accumulation, which implies the build up of a large seismic hazard.

Since the 1960's, many researchers have investigated the hypothesis that rates of tectonic deformation and long-term average erosion are strongly related. Many studies have addressed the balance of erosion and tectonic uplift in the central and southern Oregon Coast Range. In this part of the range, the topography has a characteristic morphology, with convex ridge tops dominated by soil creep processes and steep sideslopes, where small soil slips and landslides dominate (Roering et al., 1999). Near the terminus of steep, sideslopes, in steep, unchanneled valleys (topographically-defined hollows), soils accumulate and thicken over long time periods. These convergent parts of the landscape also tend to become saturated during rainfall events. The combination of thick soil and frequent saturation tends to favor these parts of the landscape for episodic shallow landsliding. As a result, hillslope erosion rate is highly stochastic over human timescales, but when averaged over thousands of years the landscape appears to be eroding at roughly the same rate, 0.1 to 0.2 mm/yr (Heimsath et al., 2001). Reneau and Dietrich (1989) estimate average hillslope erosion rates of 0.07 mm/yr over the last 4,000 to 15,000 years from analysis of colluvial deposition in hollows or topographic depressions. Sediment yield measurements from several Coast Range basins indicate similar rates of erosion between 0.05 and 0.08 mm/yr (e.g. Brown and Krygier, 1971; Beschta, 1978). These findings suggest that the portions of the landscape in the Oregon Coast Range are lowering at a similar rate of 0.05 to 0.2 mm/yr. These studies do not reflect millennial-scale variations in process rates related to climate change. Recent evidence (Long et al., 1998, Roering and Gerber, 2005) suggests that episodic fires may be a significant mechanism of sediment production because the incineration and removal of vegetation on steep slopes can cause extensive transport via dry ravel (bouncing, sliding, and rolling of grains). In the early Holocene (~8,000 ya), fires were much more frequent (~110-yr return interval) than recent times, suggesting that the soil mantle may have been much thinner and less continuous than today.

In the Oregon Coast Range, stream incision or (fluvial bedrock incision) rates are spatially variable, but approach 0.2 mm/yr to 2.0 mm/yr in regions where estimated hillslope erosion rates are 0.1 mm/yr (Reneau and Dietrich, 1991). This disparity may indicate that the Oregon Coast Range is not in strict dynamic equilibrium. Alternatively, the factor of 2 to 3 difference may reflect errors associated with measurements, dating errors, or it may reflect tectonic or climatic factors that cause these rates to be disparate on a short time scale. Although, deep-seated landslides make-up 30% of the land surface in certain portions of the Oregon Coast Range, their role in landscape evolution is unclear. In areas with a high frequency of large landslides, local topographic relief is depressed, suggesting that these features may limit topographic development. The notion of steady state topography in the Oregon Coast Range requires further examination.

Analysis of pollen and plant fossils from Little Lake, Oregon, provides a record of climatic history in the Oregon Coast Range (Worona and Whitlock, 1995). The following table indicates the climatic trends. The Oregon Coast Range supported few if any glaciers during the last major glacial period, which has important implications for geomorphic and tectonic interpretations (Baldwin, 1993). Notably, Reneau and Dietrich (1991) indicate an abundance of basal carbon dates between 4,000 and 7,500 years old, which corresponds with a period of cold and moist conditions that followed a several thousand year period of warm and dry conditions (Worona and Whitlock, 1995). This observation indicates that climatic variation may influence rates of erosion and sedimentation. The influence of climate and human factors, such as timber harvesting, on erosion is currently being investigated in the Coast Range. Recent studies have found that the coincidence of forest removal and high intensity rainfall events can significantly increase the number of shallow landslides (Montgomery et al., 2000). The results of these and other studies are important for future land management decisions.

Brief Climatic History of Little Lake. Oregon Coast Range *(Worona and Whitlock, 1995)*

Rainfall = 150 cm/yr (75-80% occurs Oct-Mar)
Unglaciated during the Fraser glaciation (ice 320 km north in Wash.)

Yr. B.P. Characteristics	
42,000-25,000	Cooler, wetter than today (at least 3°C cooler) consistent all along the Oregon coast.
25,000-13,000	Colder, drier, Oregon Coast Ranges supported small if any glaciers. (7-14°C cooler, 50% of today's rainfall)
16,000-13,500	Small warming trend, increased moisture 11,000-10,000 Colder, brief reversal
10,160-9,000	Warm, dry conditions; intensified summer droughts and widespread fires; increased solar radiation from increased tilt of the earth.
6,000-3,000	Cool, moist climate much like today
3,000-2,000	Reduced moisture (somewhat) and cooling 2,000-> Somewhat drier, fires?

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Oligocene Intrusions of the Central Oregon Coast Range: Petrology, geochemistry, and geochronology

(Oxford, OSU M.S. Thesis, 2009)

These intrusions play a critical geomorphic role in shaping the evolution of the Oregon Coast Range as they tend to form linear ridges of high relief and provide resistant bedrock that retards bedrock river incision.

The Early Oligocene Oregon Coast Range Intrusions (OCRI) consist of gabbroic rocks and lesser alkalic intrusive bodies that were emplaced in marine sedimentary units and volcanic sequences within a Tertiary Cascadia forearc basin. The alkalic intrusions include nepheline syenite, camptonite, and alkaline basalt. The gabbros occur as dikes and differentiated sills. Presently, erosional remnants of the intrusions underlie much of the high topography along the axis of the central Oregon Coast Range. The intrusive suite is most likely associated with Tertiary oblique rifting of the North America continental margin. Dextral shear and extension along the continental margin may have been a consequence of northeast-directed oblique Farallon plate convergence. The OCRI are part of a long-lived (42-30 Ma) magmatic forearc province that includes the Yachats Basalt and Cascade Head Basalt. The timing of Cascadia forearc magmatism correlates with a significant decrease in convergence rates between the Farallon and North American plates from 42 to 28 Ma. The OCRI are also contemporaneous with magmatism that occurred over a broad area of the Pacific Northwest (e.g. Western Cascades, John Day Formation).

New radiometric age data acquired from the Ar-Ar incremental heating experiments indicate that OCRI magmatism occurred between ~36 to 32 Ma; a longer interval than previously thought. The alkaline OCRI are closely associated with the late Eocene OIB-like Yachats Basalt and Cascade Head Basalt forearc volcanic centers in both space and time. In addition, trace element geochemical data suggest similar parental magma sources for the alkaline OCRI and the forearc volcanic centers.

The alkaline OCRI parental magmas were generated from small degrees of partial melting of an enriched OIB-like mantle source. There are two possible mantle sources for the alkaline OCRI: 1) An enriched lithospheric Siletzia mantle source that was previously metasomatized by deep-sourced alkaline melts or 2) upwelling asthenospheric mantle from beneath the subducting slab which would require a slab window. If the alkaline OCRI were derived from the lithospheric Siletzia mantle, then the mantle wedge would have been significantly thicker and possibly hotter during the Tertiary. Presently, the crustal rocks of Siletzia rest directly on the subducting Juan de Fuca plate. The tholeiitic OCRI gabbros are a separate, more widespread, and voluminous pulse of forearc magmatism that was contemporaneous with alkaline OCRI and Cascade Head Basalt magmatism. The Ar-Ar geochronology and previous K-Ar age data reveal that the gabbroic OCRI magmatism was short-lived. The Marys Peak sill and nearby dikes were emplaced between approximately 32 and 33 Ma. The major element geochemistry of the gabbros indicates that their magmatic evolution was driven by crystal fractionation processes at crustal levels. In contrast with the alkaline OCRI, the gabbros are characterized by tholeiitic compositions with lower degrees of incompatible element enrichment. Their trace element chemistry also displays an arc-like signature which indicates the involvement of a subduction-modified mantle source component in their petrogenesis.

The formation of the OCRI gabbroic magmas involved upwelling and decompressional melting within the mantle wedge. Oligocene forearc extension may have become more widespread for a short duration (~2 m.y.) which aided the ascension of relatively dense, iron-rich gabbroic OCRI magmas. During this period, the mantle wedge beneath the forearc experienced larger degrees of decompressional partial melting allowing for the generation of voluminous tholeiitic magmas. Since the gabbros are in close proximity to the Western Cascades arc, their petrogenesis was also linked to the Cascades subduction system, as indicated by their trace element geochemistry. Overall, the OCRI represent the final episode of widespread forearc magmatism and record significant changes in tectonic interactions between the Farallon and North America plates.

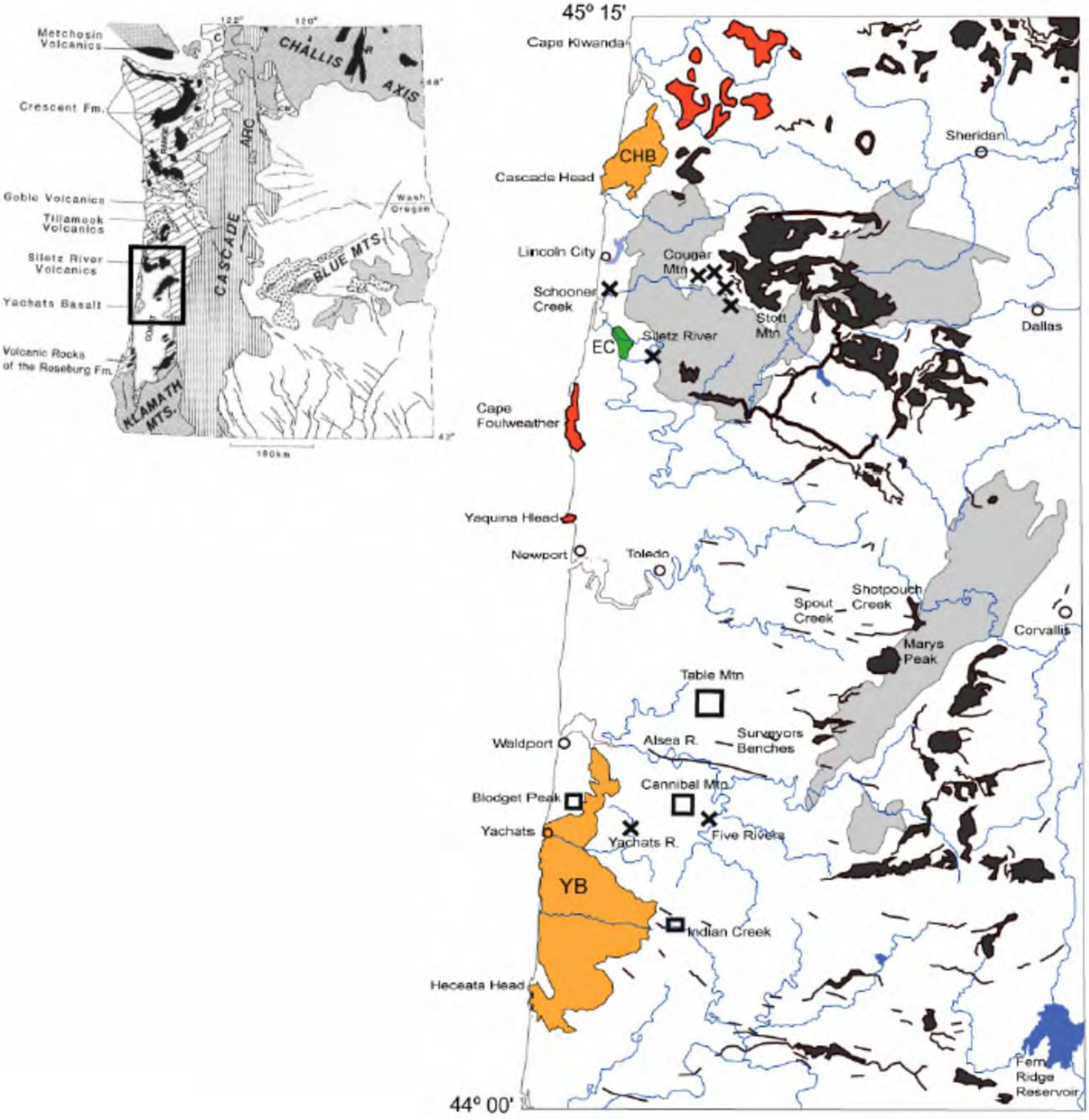
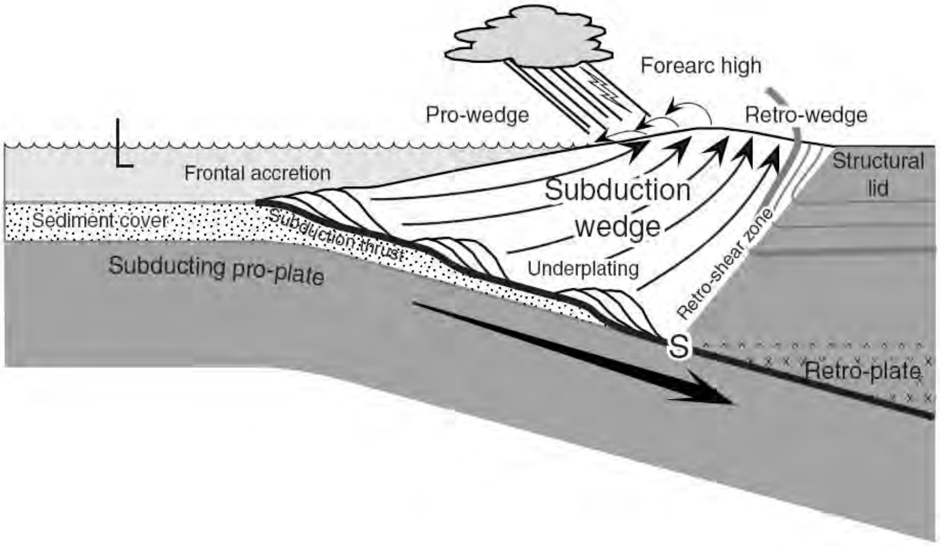
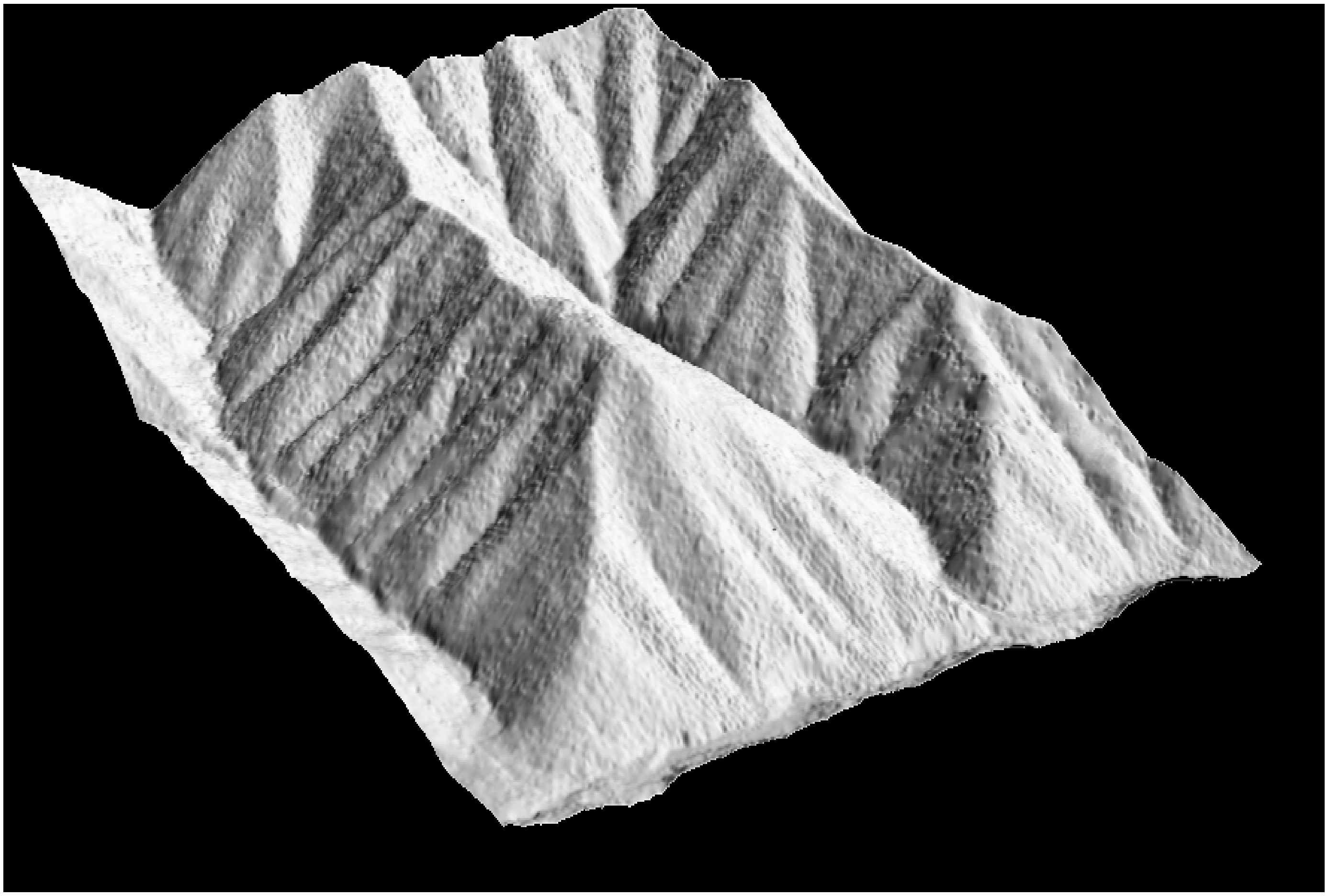
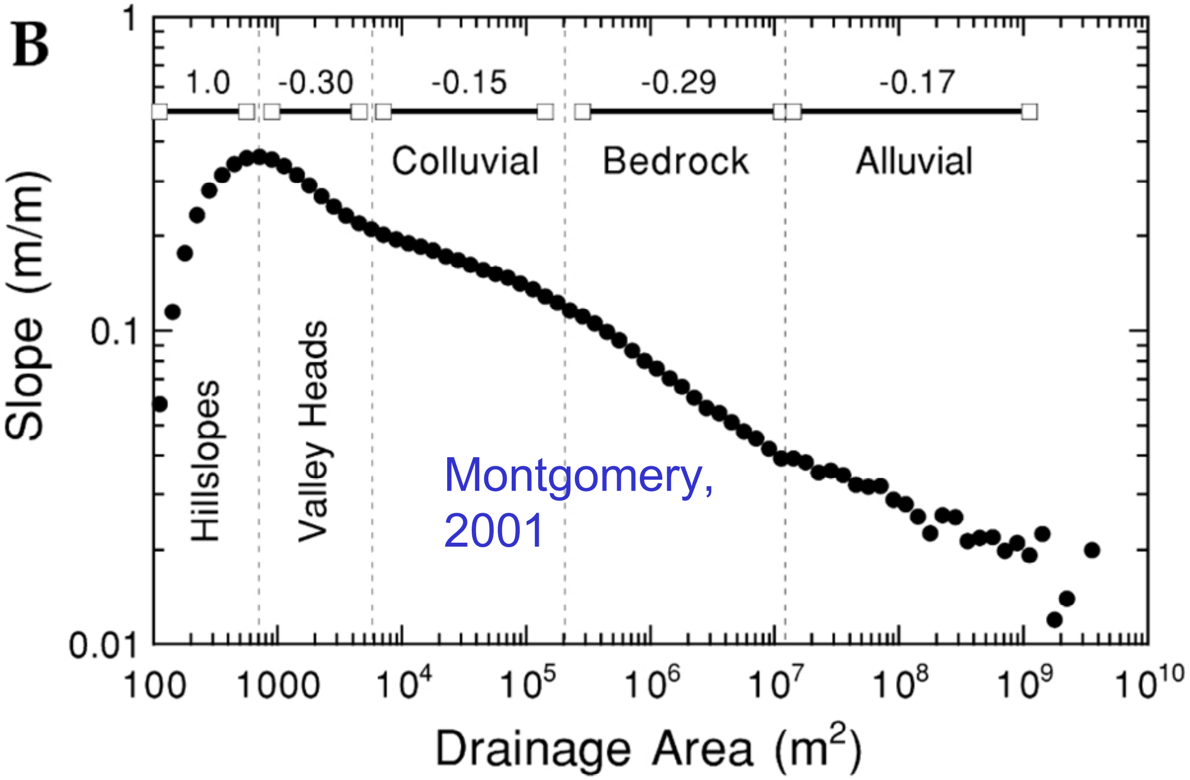


Figure 1: Left: Geologic and tectonic map of the Pacific Northwest from Wells et al. (1984). Major Tertiary Cascadia forearc volcanic centers and Coast Range basement rocks are labeled. Exposures of contemporaneous John Day backarc volcanic deposits are located in the Blue Mountains. The box encloses the area of study. Right: Distribution of igneous rocks within the area of study. Boxes, sampled nepheline syenite intrusions; "X's", sampled camptonite and alkaline basalt intrusions; black bodies, gabbroic intrusions; red bodies, Miocene Columbia River Basalts; light gray areas, exposures of Siletz River Volcanic basement rocks; CHB, Cascade Head Basalt; YB, Yachats Basalt; EC, extrusive camptonite. Figure modified from Snavley and Wagner (1961). Additional information added from Snavely et al. (1976) a, b; Snavely et al. (1968); and Davis et al. (1995).

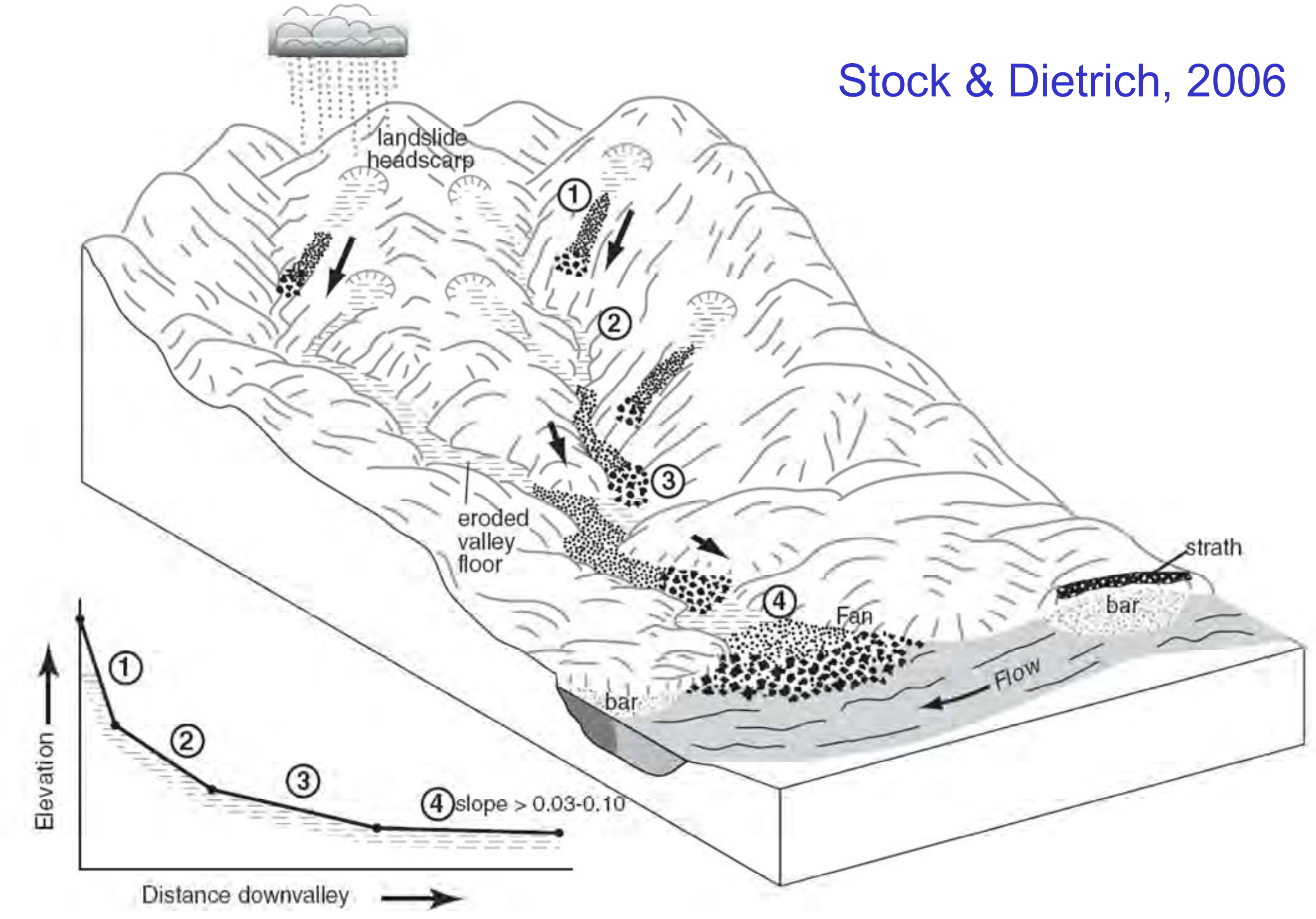

Forearc high
Pro-wedge
Retro-wedge
Frontal accretion
Structural lid
Subduction wedge
Sediment cover
Subduction thrust
Subducting pro-plate
Underplating
Retro-shear zone
S
Retro-plate



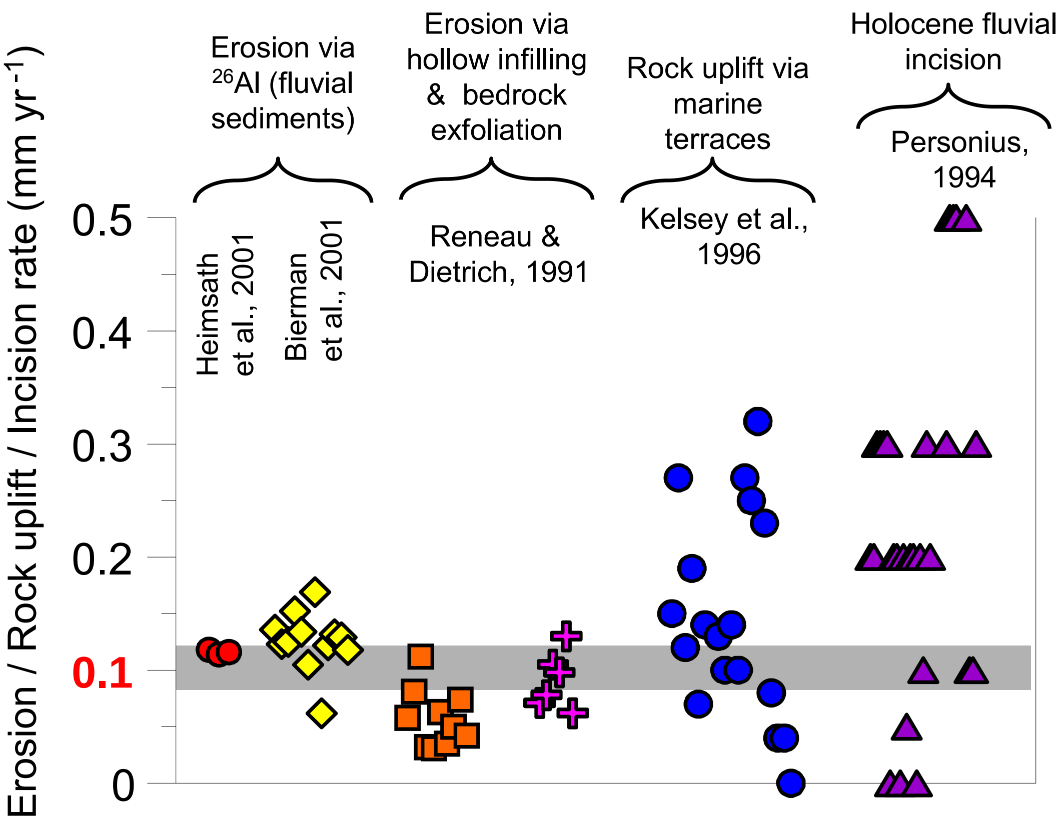

Washington
Oregon
Portland
Oregon Coast Range
Alsea River
McKenzie River
Siuslaw River
Eugene
Umpqua River
Willamette River
N
65 km

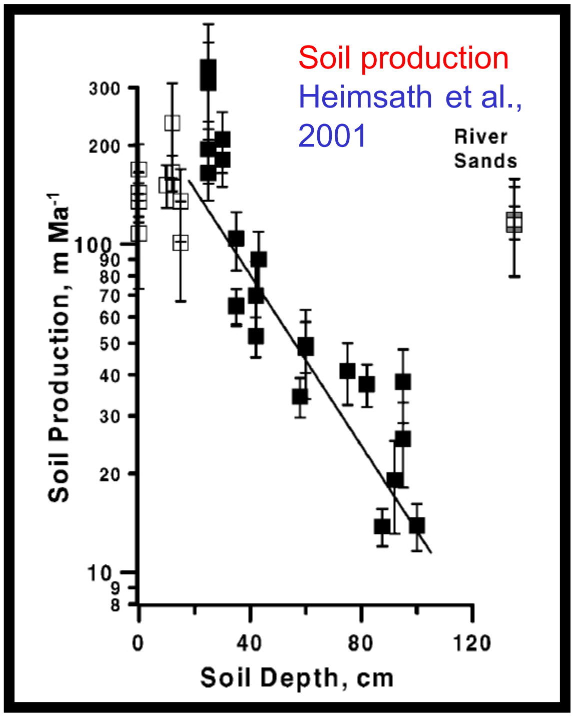


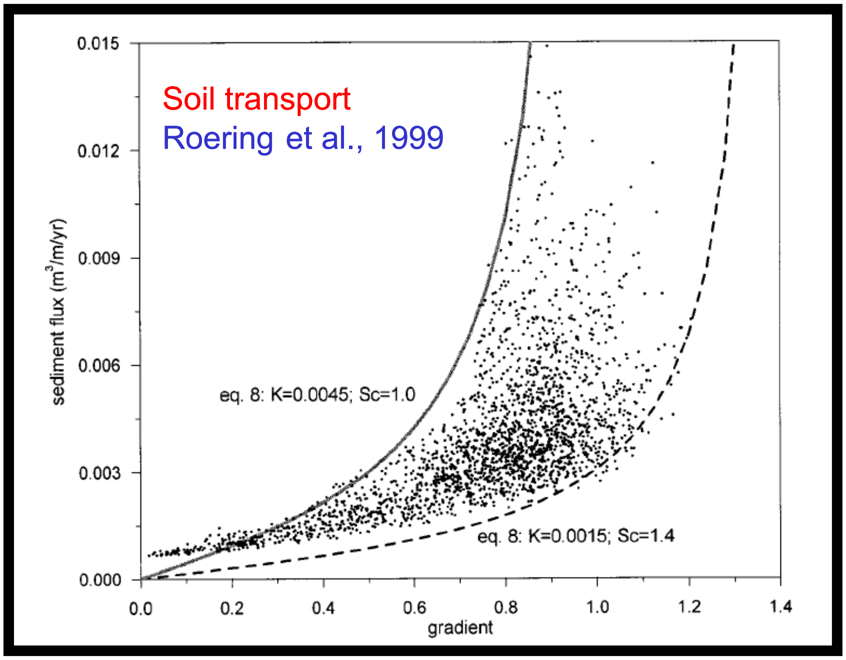
Montgomery, 2001

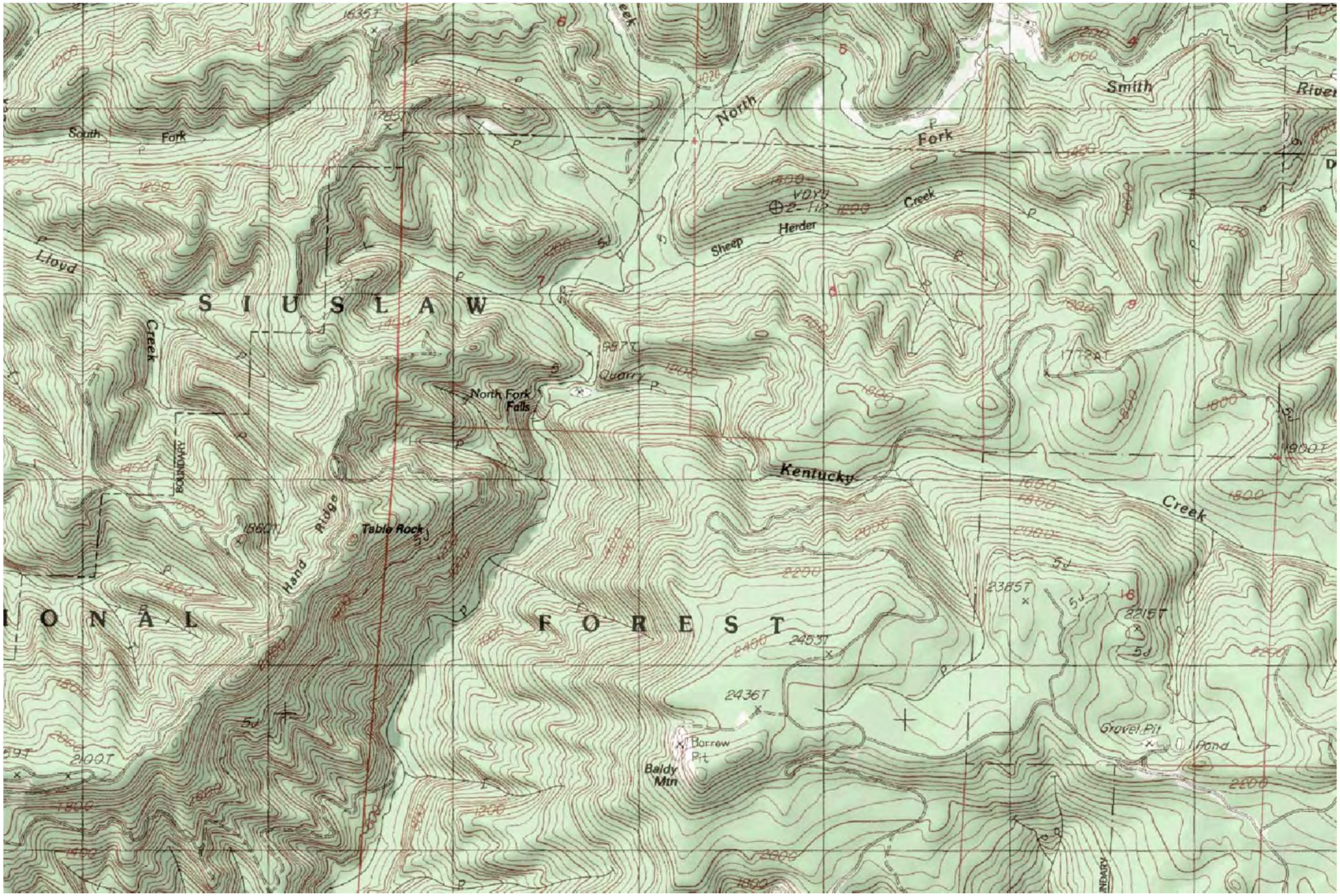


Stock & Dietrich, 2006

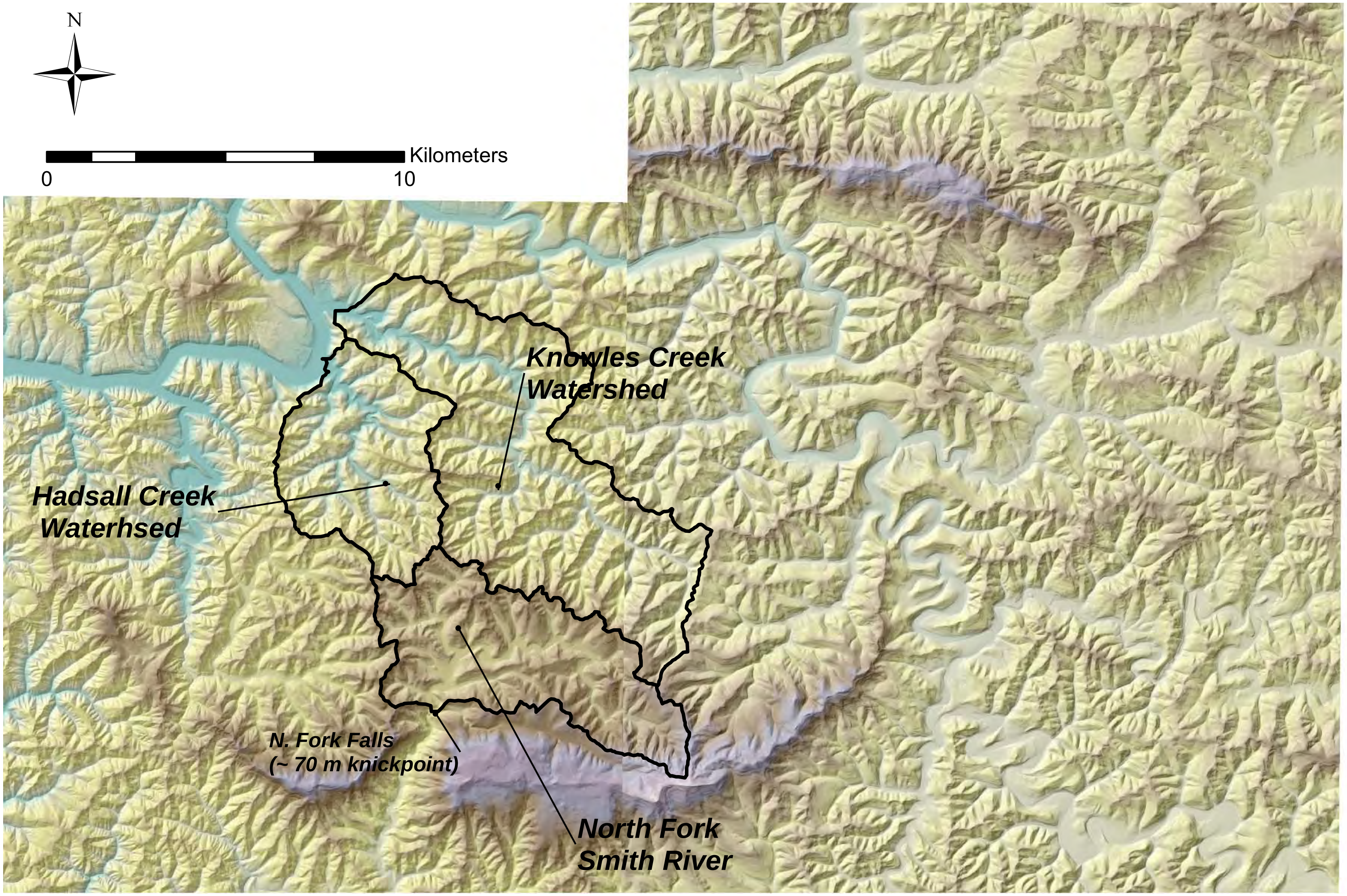

Erosion / Rock uplift / Incision rate (mm yr-1)
0.5
0.4
0.3
0.2
0.1
0
Erosion via 26Al (fluvial sediments)
Heimsath et al., 2001
Bierman et al., 2001
Erosion via hollow infilling & bedrock exfoliation
Reneau & Dietrich, 1991
Rock uplift via marine terraces
Kelsey et al., 1996
Holocene fluvial incision
Personius, 1994

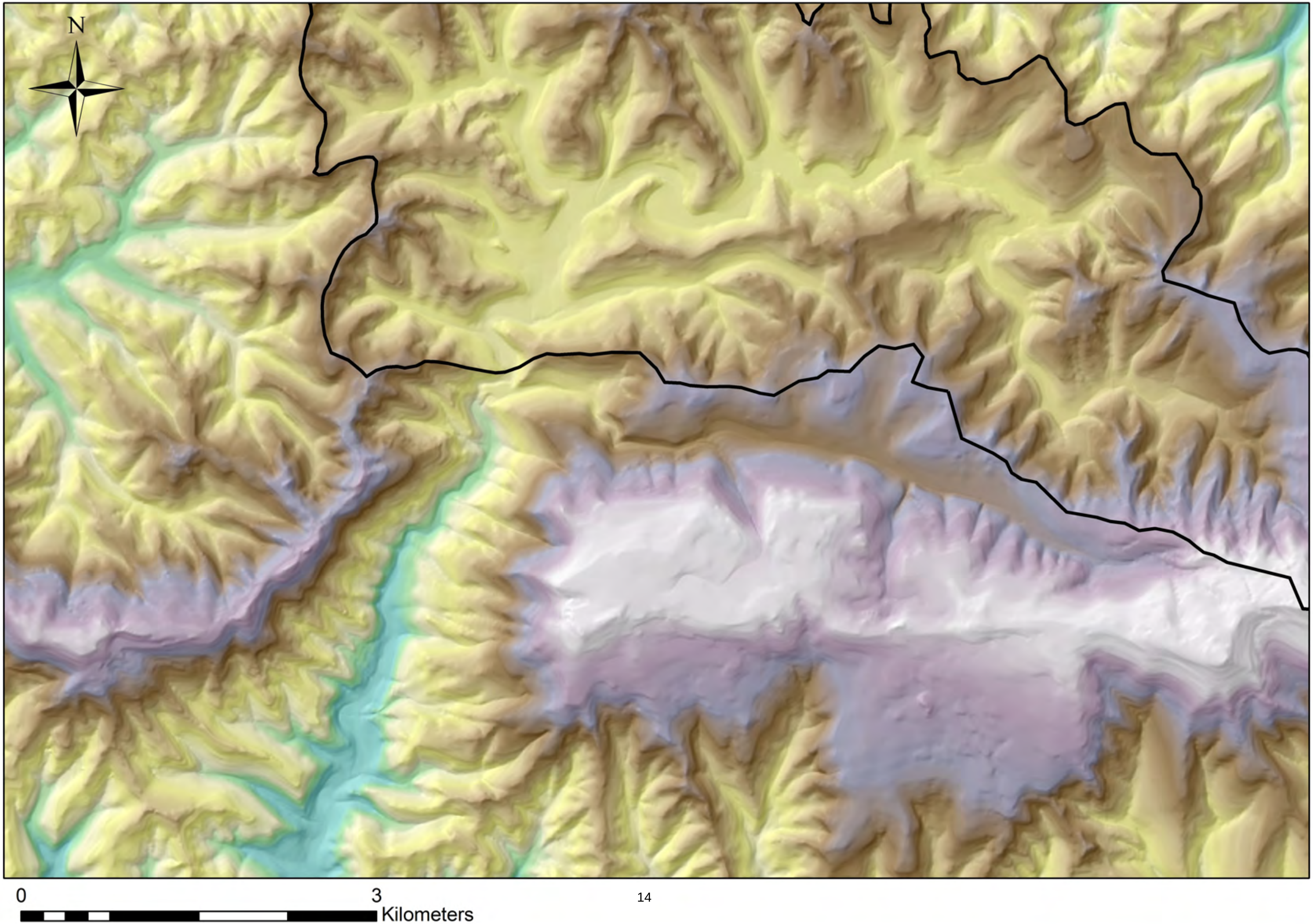

Soil production
Heimsath et al., 2001
River Sands
Soil Production, m Ma-1
300
200
100
90
80
70
60
50
40
30
20
10
9
8
0
40
80
120
Soil Depth, cm


Soil transport
Roering et al., 1999
sediment flux (m3/m/yr)
0.015
0.012
0.009
0.006
0.003
0.000
eq. 8: K=0.0045; Sc=1.0
eq. 8: K=0.0015; Sc=1.4
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
gradient



1635T
South Fork
785
North Fork
Smith River
Sheep Herder Creek
VDY9
2-112
Lloyd
SIUSLAW
Creek
987T
Quarry
North Fork Falls
1772T
1900T
BOUNDARY
Kentucky Creek
1860T
Hand Ridge
Table Rock
2385T
2215T
ONAL
FOREST
2453T
2436T
2100T
Borrow Pit
Baldy Mtn
Gravel Pit
Pond


N
Kilometers
0
10
Knowles Creek
Watershed
Hadsall Creek
Waterhsed
N. Fork Falls
(~ 70 m knickpoint)
North Fork
Smith River


N
0
3
Kilometers

Persistence of waterfalls in fractured rock

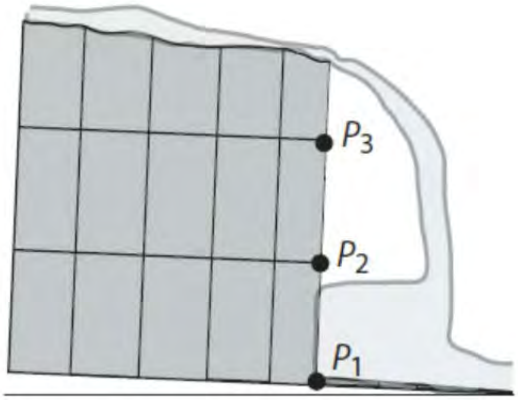


Figure 2. Schematic cartoon showing fractured basalt and three potential points for rotational failure. Two perpendicular joint sets are shown in the schematic, and the third is parallel to the page.

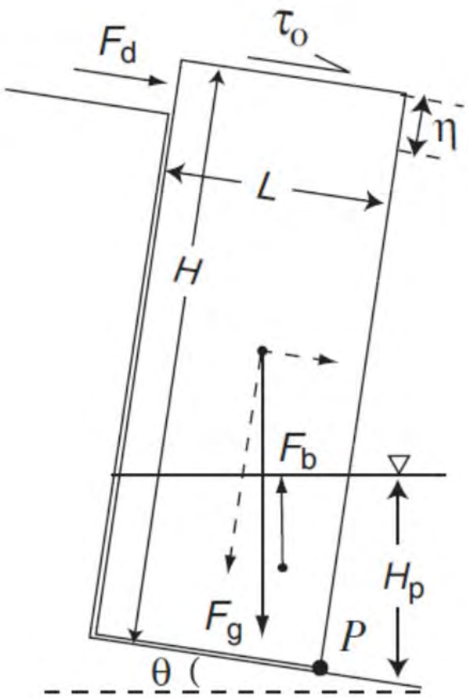


Figure 3. Schematic showing the forces on a rectangular column of rock. See text and notation list for details.

Michael P. Lamb† and William E. Dietrich

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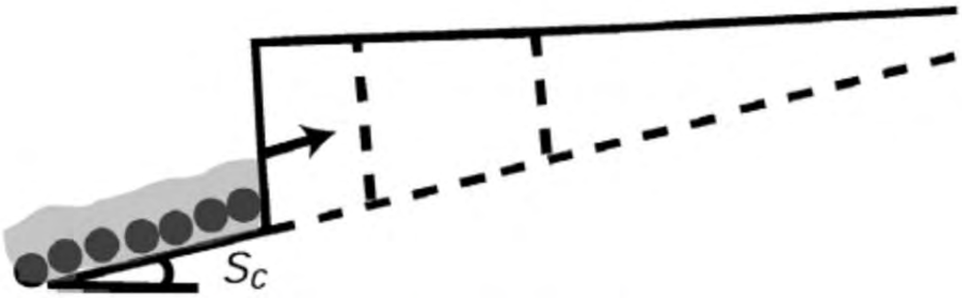

Figure 2. Schematic of upslope headwall propagation due to seepage erosion, illustrating the necessary condition of debris removal. If the discharge is not sufficient to transport collapsed debris at a given slope, the bed will aggrade until the slope surpasses the critical slope necessary for transport. If this critical slope S_c is greater than the regional topographic slope, then the headwall will diminish in height as it propagates upslope, eventually leading to the demise of the canyon.

Citation: Lamb, M. P., A. D. Howard, J. Johnson, K. X. Whipple, W. E. Dietrich, and J. T. Perron (2006), Can springs cut canyons into rock?, *J. Geophys. Res.*, *111*, E07002, doi:10.1029/2005JE002663.

GSA Bulletin; March 2000; v. 112; no. 3; p. 490–503;

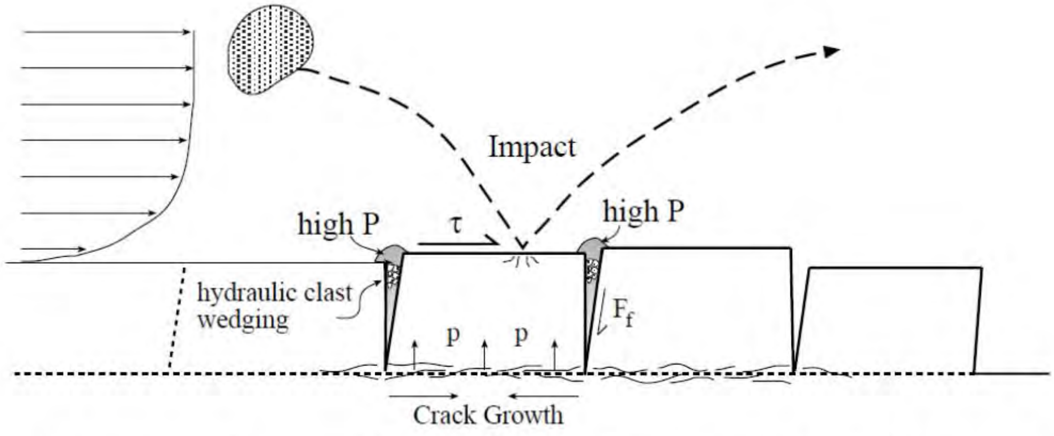

Figure 4. Schematic illustration of the processes and forces contributing to erosion by plucking. Impacts by large saltating grains produce some direct abrasion damage but contribute most importantly to the generation of stresses that drive the crack propagation necessary to loosen joint blocks. Hydraulic clast wedging works to further open cracks. Surface drag forces and differential pressures across the block act to lift loosened blocks. Where the downstream neighbor of a block has previously been removed, both rotation and sliding become possible, and extraction is greatly facilitated.

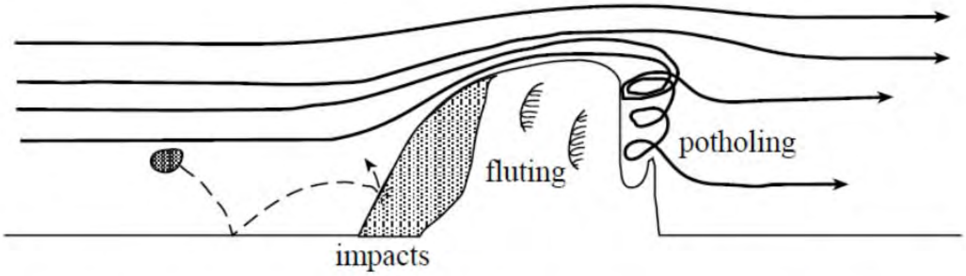

Figure 5. Schematic illustration of the processes contributing to erosion by abrasion. Bedload and the coarsest suspended-load grains are strongly decoupled from the fluid flow and impact the upstream faces of protuberances and obstructions (shaded region). In this zone, surfaces are observed to be smooth and polished, but little abrasion damage appears to occur (see data in Hancock et al., 1998). Fine-scaled flutes and ripples adorn the flanks of massive protuberances where flow separation induces tight, stream-wise vortices (see Figs. 2A and 6A). Large, often coalescing potholes characterize the lee side of obstructions, protuberances, and knickpoints (see Figs. 2B and 6B). The complete obliteration of massive, very hard rocks in these potholed zones testifies to the awesome erosive power of the intense vortices shed in the lee of obstructions (see Fig. 2B).