

Young evidences in an ancient landscape: part 2—high-altitude sapping

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Pronounced erosional features consistent with formation by ground water sapping were mapped in a 25,000-km² section of the sedimentary Ridge and Valley area of the Appalachian Mountains in Pennsylvania. These features were evaluated by criteria known to cause hydraulic sapping—a natural erosional process initiated by water levels receding after complete inundation of sediment. Over 600 saps were mapped and carefully measured, revealing easily identifiable features known to be caused by ground water sapping. Supposedly very old, these saps exhibited distinct topographic forms, geometry, location, elevation, and profile. The sap formations studied reside at a high elevation in relation to the ridge they formed under—some even existing on either side of the same ridge at the highest possible elevation. Sufficient ground water to create saps would not be expected at these elevations. The study area was never glaciated, ruling out formation by impounded melt water. The traditional theory, that millions of years of erosion acting on the originally ‘Himalayan’-sized Appalachians reduced them to their present size, cannot explain these distinct and repetitive structures. These saps are better explained as recent formations created by the recessional stage of a catastrophic inundation.

Erosion by sapping is caused by focused ground water discharge from the lower side of a saturated embankment of sediment.¹ During the discharge process, sediment is removed along with the water. Completely submersed sediments have all interstitial spaces occupied by water, retarding compaction and lithification (diagenesis).² As the inundating water elevation lowers, the unconsolidated sediment particles are carried out at the low side of the now emerging shoreline by seeping action of the entrained water. This erodes the hillside from underneath, undermining the overlaying layer, which slumps into the lower discharge of water,³ carrying the sediment away. The process continues until the entrained water at the higher elevations in the emerging sedimentary hillside has mostly discharged.

Examples of sapping can be found in the southwest United States where lack of vegetation, extensive sandstone landscapes, and limited rainfall make ground water saps easier to observe. The Escalante River basin in Utah is a good illustration of this phenomenon (figure 1). The lack of vegetation from limited rainfall in a sandstone landscape encourages the formation of undercutting on the lower slopes with minimal evidence of upslope runoff gullies or drainage basins. Steve Austin has postulated that this may be one mechanism that formed the side canyons of the Grand Canyon,⁴ as these canyons are characterised by short lateral distance, no head end gullies, under-fit (or no) streams or seeps, and are amphitheatre headed.

Sediment tank experiments have demonstrated that the sapping process starts with random breakouts of water occurring at areas of weakness in the saturated sediment. As the seeps develop, the minor erosion causes a slight

deflection and concentration of ground water discharge⁵ from the surrounding sediment by providing a shortened path of escape. Erosion into the hill creates easier paths of escape for adjoining seeps, causing the area of erosion to progress not only into the hillside, but laterally to the left and right as well. This causes the distinguishing ‘amphitheatre headed’ characteristic of saps,⁶ resulting in bowl-shaped depressions that often have ratios of length to width near 1:1. It also explains why there are no head end (inlet) streams, and why there are no drainage basins. The erosion is from below and from within—not from the top down.

When first forming, new saps consume each other along the seepage line, resulting in lateral lines of saps with fairly uniform spacing and similar sizes (figure 2). The process is self-defining, creating recognisable patterns, which are the focus of this paper.

To summarise, saps are unique erosional features formed by:

- dropping water elevation
- seepage (sapping) of non-cemented saturated sediment
- erosion from underneath, not from surface run-off.

Saps can be identified by:

- no inlet water course
- no outlet water course except for intermittent streams during heavy precipitation or occasional springs
- a bowl shape (amphitheatre headed)
- a distinct discharge point or throat
- side-by-side alignment along similar elevation at regular intervals.

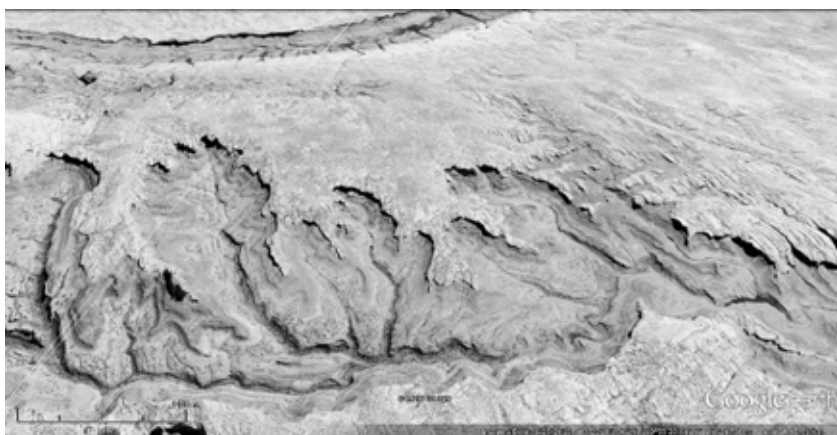


Figure 1. Sap formation in the Escalante River Basin in Utah, US (Google Earth Pro, image date 25 June 2013, generated 2 April 2016)

Study area and its lithology

For this study we carefully mapped features that appeared to be the result of hydraulic sapping in the 25,000-km² area of the sedimentary Ridge and Valley Province⁷ of the Appalachian Mountains in Pennsylvania. The ridges are formed from resistant quartzitic sandstone underlain by mudrocks and carbonates.⁸ The area was not glaciated⁹ and recent geologic processes are not attributed to this area.

The Ridge and Valley Province is comprised of systemic units ranging from Cambrian to Pennsylvanian, and especially Silurian and Ordovician,¹⁰ meaning none of the area is thought to be younger than 290 Ma old.

The folded strata forming the ridges are generally comprised of Silurian red and grey sandstone, conglomerate, shale, and limestone overlain on lower Ordovician shale, limestone, dolomite, and sandstone.¹¹ The lower Silurian deposits consist of rippled sandstone, channel-fill sandstone, planar-bedded or parallel-laminated sandstone, and other combinations of sandstone and shale deposited cyclicly.¹² Upper Silurian strata shift to limestones and dolomites.¹³ Sand-sized sediment favourable for sap formation is present in abundance.

Methodology

Identification and measurement of each suspected sap was accomplished using commercially available topographical mapping software.¹⁴ We

did not map low altitude saps or the sapping features east of the Susquehanna River in the anthracite coal region. We did identify saps in this area, but they were less numerous and are the subject of further research.

Figure 3 demonstrates how each sap was tagged with a label, mapped and measured. The drainage basin contributory to each sapping formation was overdrawn with a polygon traced at right angles to the topographic contour lines. We did not include the area below the throat discharge of the sap, but used the adjoining ‘knobs’ at either side of the sap as a self-defining lower limit of

the drainage basin mapping. Most of the structures were easy to delineate. The mapping software automatically tagged each drainage basin polygon with the perimeter and area uphill of each sap.

A dimension line was then drawn across the widest part of the lower side of each sap connecting the high point of each knob to determine its width. This line was also used as a section line to draw a profile across the throat and calculate the lowest elevation along this line. We defined



Figure 2. A line of saps in Group 11 looking southwest. Note the even spacing and linear arrangement of the saps along the same elevation. There are no inlet streams or downslope discharge streams. The ridge on the left is marked by an unvegetated outcrop of resistant rock. The sediment filled, relatively flat valley in the centre is marked by farmland (landsat source image generated three dimensionally by Google Earth Pro on 23 May 2015).

and recorded this as the ‘Invert at Throat’. This technique provided a consistent methodology for establishing a ‘discharge’ elevation from the sap.

The highest elevation of the ridge above the sap was recorded. The highest area eroded by the sap and the lowest area eroded below the throat discharge were also recorded. These last two measurements required considerable interpretation of the contour lines and are subject to an accuracy of ± 20 m at best. The most difficult observation was the elevation of lowest influence caused by each sap because there were occasional gullies or valleys extending well down the slope from either original or modern run-off. However, many saps did have a recognisable lower limit to their influence on the surrounding topography—an indication that they stopped forming and are relic landforms. Further, an accuracy of ± 1 m for ridge elevation and width of the sap, ± 10 m for ridge sag and ± 0.01 km² for drainage area, was maintained.

Types of saps

The saps occur in several general forms. The classic amphitheatre-headed sap confined by elevated landmasses or ‘knobs’ at one or both sides of the discharge area was called ‘Type 1’. The saps that had no knobs, but otherwise maintained most of the other features just discussed, were called ‘Type 2’ (figure 4). We did not try to map every Type 2 sap because there is a point where they become indistinguishable from surface erosional features. We did map Type 2 saps where they were intermingled with the predominant Type 1 saps or where they were arranged linearly because of the higher certainty that they were true

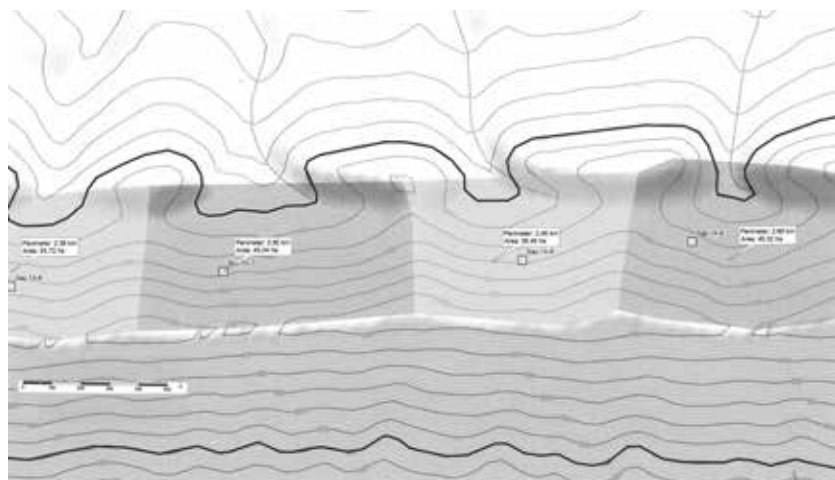


Figure 3. A relief map of typical saps studied. The drainage areas are shaded, perimeter and area measurements are added and the 550 m contour line is highlighted on either side of the ridge (image derived from Delorme Topo USA 8.0 software, 25 m contour interval, overdrawn by author).

saps and not surface erosion. The measurements of the less-defined forms of Type 2 saps are less reliable.

We infrequently observed some saps that were elongated (T-shaped) or contained double bowls. We called these ‘Type 3’ and ‘Type 4’ respectively. These were not found in great number. We felt it was appropriate to record these occasional formations when grouped with Type 1 saps even though they are outliers to the classic shape.

We also excluded any saps located well below the ridge line, usually at an elevation below 400 m ASL (above sea level) because of the general nature of stream beds, plains, and general erosion prevalent below this elevation that made detailed mapping difficult. There are clearly some lines of ‘low altitude’ saps that exist at the base of the mountains, but they are not the topic of this paper.

Observational bias

Many saps were well defined and could be readily identified and measured. Others required subjective evaluation. To eliminate as much observational bias as possible, we used the following procedures:

- **Identification:** after a first pass through the study area, we went back and systematically scanned from west to east along grid lines from north to south at a high zoom factor¹⁵ and preliminarily marked each suspected sap. This zoomed-in study of 15–45 km² areas removed our ability to see regional patterns. It also revealed many smaller saps that cannot be seen at larger scales. Hundreds of well-defined saps were less than 1 km² in total drainage area.
- **Non-inclusion:** during the identification process, we identified hundreds of other possible saps we did not include in our study. Many of these appeared to be partially formed without enough characteristic features to accurately measure. Some could have been caused by surface run-off. Some long linear Type 3 saps followed double-ridge structures with active streams and geometry far removed from the ‘classic’ Type 1 saps. We did include Type 3 saps that were not obviously controlled by long streams. We intentionally did not include low-altitude saps occurring just above the adjoining valley floors.
- **Measurement:** several ‘self-defining’ measurement techniques were established to quantify each sap:

Drainage basin area: we mapped the full contributory area above each

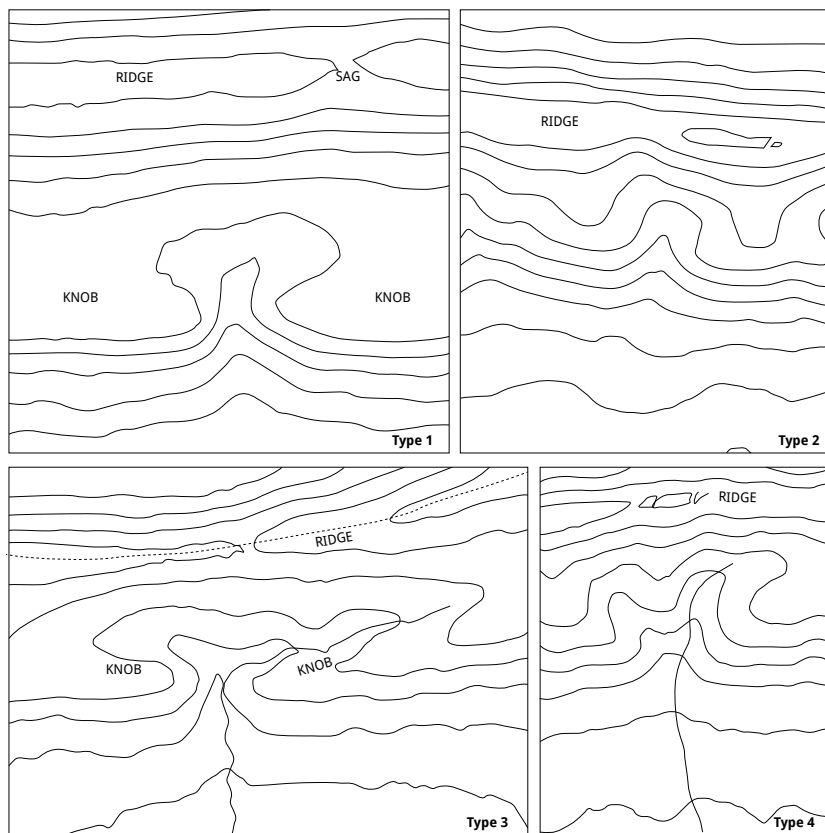


Figure 4. General shapes of Type 1, 2, 3, and 4 saps (image derived from Delorme Topo USA 8.0 software, 25 m contour interval, labelled by author).

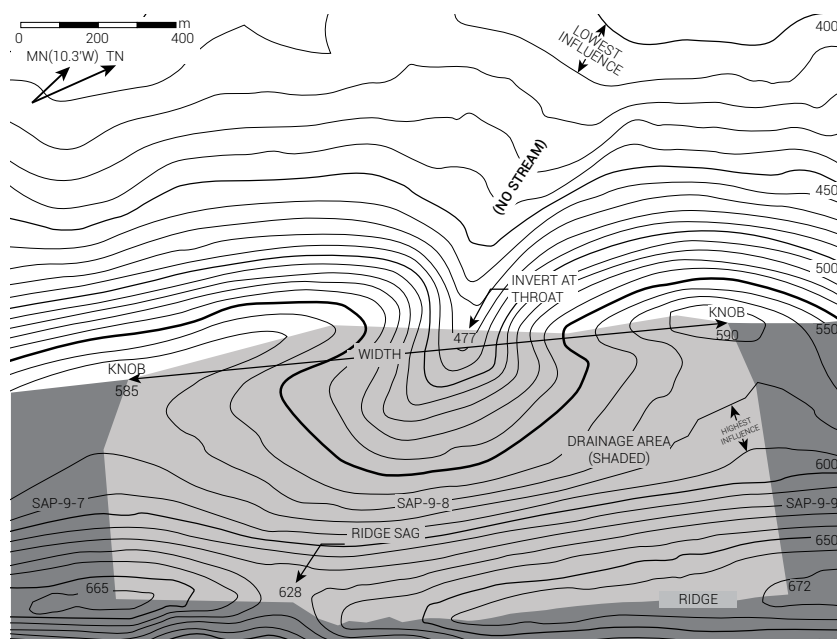


Figure 5. A relief map of a typical sap (Sap #8 in Group 9) used to illustrate how measurements were taken. Elevations are in metres above sea level and the 550 m contour is highlighted (image derived from Delorme Topo USA 8.0 software, overdrawn by Matt Fink).

feature from the throat of the sap all the way up to the ridge line, even though some saps did not extend all the way to the ridge line. Almost all the saps are bounded on either side by the next sap, so this technique gives an absolute maximum of drainage area available to influence the formation of the sap by surface or ground water.

Sap width: we used a line drawn from the highest point of each knob of Type 1 saps to determine width. This allowed a consistent and self-defining point of geometry to be used for measurement, even though the sap discharge continued well below this line. Type 2 saps could not be measured in this manner, making the measurement of their widths and inverts much more subjective.

Throat invert: we used the same width measurement line to generate a profile across the discharge throat of the sap. The mapping software automatically calculated the lowest elevation along this line, which was recorded as the invert of the sap throat even though the sap discharge valley continued well below this line.

- **Ridge sag:** the upper extent of the drainage basin often aligned with a sag in the ridge (discussed in detail later). This was not obvious until the drainage basin contributory to each sap was delineated with a polygon (figures 3 and 5). This mapping revealed a strong correlation between ridge sags and saps in more than half of the saps.

- **Naming:** many of the saps near populated areas were named, such as 'Black Gap' or 'Bear Gap'. We did not use this as a method to locate saps, but it confirmed that they are identifiable features with enough prominence to have been named.¹⁶

Observations

Figure 6 maps the location of each sap for which we obtained measurements. We were able to identify 379 Type 1 sapping structures,

Table 1. Average sap measurements by type

Description	Throat Invert (m ASL)	Ridge Sag (m)	Ridge Height (m ASL)	Highest Influence (m ASL)	Lowest Influence (m ASL)	Area (km ²)	Width (km)	Ratio of Area to Width (km ² /km)
All Type 1 saps	430.13	8.13	625.42	515.20	319.95	1.21	1.31	0.93
Type 1 saps with no stream	432.43	5.87	613.93	504.18	340.61	0.86	1.05	0.82
All Type 2 saps	483.62	7.51	646.00	549.98	394.40	0.49	0.71	0.69
All Type 3 & 4 saps	420.59	15.52	620.45	521.03	292.07	2.06	2.56	0.80
Saps with stream	411.66	12.31	627.72	523.01	268.71	2.27	2.21	1.02
Saps with Intermittent stream	449.13	10.00	647.08	537.66	326.88	1.05	1.22	0.86
Saps with no stream	456.18	6.52	626.96	523.85	369.67	0.67	0.88	0.76
All saps	447.68	8.27	632.11	527.18	343.69	1.01	1.17	0.87

Table 2. Sap quantities by drainage area

Drainage Area of Sap (km ²)	Quantity of Saps	Quantity of Saps with Permanent Stream	%
1.0 or less	427	18	4.2%
1.01–2.0	109	32	29.4%
2.01–3.0	41	18	43.9%
3.01–4.0	26	13	50.0%
More than 4.0	12	12	100.0%

and these occurred on both sides of ridges and throughout the study area.

We calculated the ratio of area to width, confirming that many of the saps were near the ratio of 1 km² in area by 1 km wide—that is, bowl shaped. The average ratio was 0.87 km²/km with only 10 saps less than 0.3 km²/km and only 11 saps more than 2.0 km²/km. We used this calculation only to look for outliers and to test that the saps were not linear drainage features. Although there appear to be some outliers in the data, their effect on the analyses was not large enough to warrant excluding any of the raw data collected.

We grouped the saps with similar characteristics and averaged the measurements to produce table 1. Table 1 confirms that saps with a stream have the lowest average throat invert and the lowest average influence below the sap. We expected this because of modern erosion and assumed we would need to exclude saps with active streams from our analysis. However, the erosion was not great enough to significantly alter the averages, and saps with permanent or intermittent streams were not excluded. This suggests that the ongoing down-cutting erosion by streams has not been occurring long enough to significantly alter the shape and elevation of the saps. If the saps were ancient relics,

modern streams in the larger ones should have deepened or elongated them, destroying their distinctive form.

We further analysed the effect of modern streams on the saps in table 2. The majority of the saps, which are the smallest saps, have few permanent streams, attesting to the fact that streams are not what formed the saps. All of the saps greater than 4 km² have a catchment area large enough

to support permanent streams from precipitation—enabling modern erosion. However, only 2% of the saps studied are this large.

During mapping, there appeared to be a bias of sap formation near elevation 500–550 m ASL. 72% of the saps had at least part of the structure at or above 500 m ASL. Saps grow downward as the sapping spring carries sediment away and they also grow upward as the headwall collapses. To arrive at an approximate starting elevation, the throat invert and the area of highest influence were averaged and the result used to produce figure 7, which graphs the quantity of saps by elevation in 40-metre increments. 80% of the saps were in the range of 402–570 m ASL, peaking at 486–525 m. Figure 7 demonstrates that the saps do have a preferred elevation for formation. The saps disappear below 366 m except for those forming just above the valley floors. There is a ‘dead band’ of no formation between 325 and 365 m. This preferred elevation for formation occurs in distinct ridges spread over 25,000 km², negating the possibility that uniform geology caused the elevation preference. The well-defined inverted ‘V’ shape of figure 7 is suggestive that a force that can arrange erosional features horizontally over vast distances, such as floodwater, would be a better explanation for the sap locations, rather than random erosion.



Figure 6. Map of the 25,000 sq km study area. The white squares label the centre of each group of saps. The black triangles are drawn to scale over each individual sap measured (image derived from Delorme Topo USA 8.0 software, overdrawn by author).

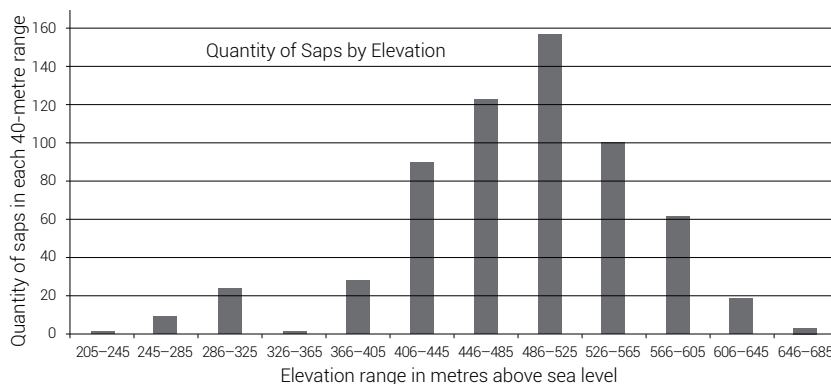


Figure 7. The quantity of saps grouped by elevation

The west edge of the Ridge and Valley Province is marked by a structural front (figure 6). North and west of the structural front, the geomorphology changes to an elevated rolling topography with a dendritic drainage pattern, mostly above 550 m. This landmass would backstop the elevated sea level of the recently opened Atlantic Ocean to the south and east.

Ridge sag

An unexpected observation developed as each sap was mapped. The uphill extent of the drainage basin often aligned exactly with heightened points on the ridge above the sap at both the right and left edge of the drainage basin (figures 3, 5 and parts of figure 4). A sag in the ridge was only recorded if the ridge elevation was lower somewhere along the ridge line of the contributory drainage area than at the ends. If the ridge was sloping overall from one edge to the other, it was not counted as ridge sag. The amount of sag in the ridge was measured in 10-m increments to identify that it did exist, rather than to try to quantify it in absolute terms. 57.7% of the saps correlated with a sag in the ridge. This raised the question of whether the sap formation caused the ridge to sag or whether another mechanism was at work, such as overtopping of the ridge by waves or tsunamic action, especially where the ridge sags were in the 20–50 m range forming more of a ‘gap’ than ‘sag’. The observation is quantifiable regardless of the mechanism that caused it.

Benched profiles

A second unanticipated finding was that the saps did not cut into the side of the mountain slope. Rather, they cut through a ‘bench’ on the side of the slopes. This is best illustrated by cross sections cut through the saps to

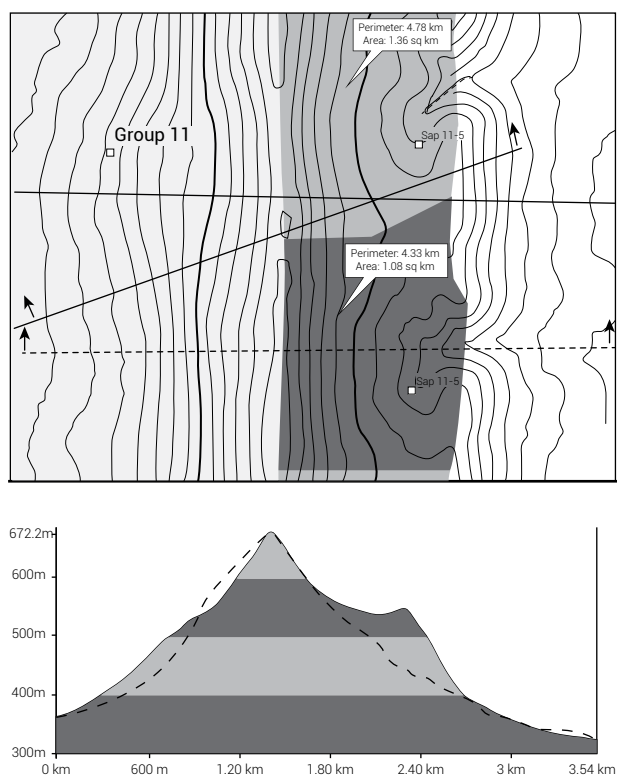


Figure 8. The upper topographical map shows where sections were cut. The 550-m ASL contour line is highlighted. The lower profiles drawn through the sap (dashed line) and through the knob (solid line) demonstrate that the saps follow the overall slope of the mountain while the area between the saps stands prominently above the expected slope (vertical exaggeration 4:1). (Images derived from Delorme Topo USA 8.0 software, overdrawn by author.)

demonstrate the effect. Figure 8 shows a typical condition where saps formed on only one side of a ridge in a raised area or ‘bench’ in the profile.

Assuming that resistant strata caused the ridge to form, a back-sloped area could result along a secondary outcrop of resistant strata further down the slope, feeding surface runoff into the saps. Dispelling that possibility, figure 9 shows a typical condition where saps formed on *opposite sides of the same ridge at the same elevation*.

Receding tides can create similar benched profiles on a smaller scale (figure 10). A receding tide with gentle wave action produced the same profile in miniature as that observed in the Appalachians (compare figure 10 with figure 2). The constant slope is interrupted by a bench that then develops knobs flanking each sap.

Figure 11 demonstrates how wave action may be a formative part of the sapping features studied. A lower sloped benched area (relative to the overall beach slope) is formed during the receding tide, possibly by shore parallel currents. The receding tide initiates sapping action. The

deepening sap areas capture the waves, diverting energy away from the knobs. The knobs survive above the surrounding topography and help funnel the erosive wave energy into the saps, reinforcing the sap formation with distinctive knobs. The scale of figure 11 is diminutive, but the resulting formations demonstrate that sapping reinforced by wave action on a receding tide can produce the distinctive formations recorded in Pennsylvania.

Discussion

For reasons discussed above, the level of 500–550 m ASL can be used as a present-day marker indicative of a rapid lowering of sea level. Below 550 m ASL, the ridges of the Ridge and Valley Province started to act as linear islands in the receding sea, changing sheet flow into channelised flow forced to run parallel to the ridges as water level dropped. Landforms indicative of the transition from sheet flow to channelised flow were also postulated just below 500 m ASL in the previously published Part 1 of this paper, based on other criteria.¹⁷

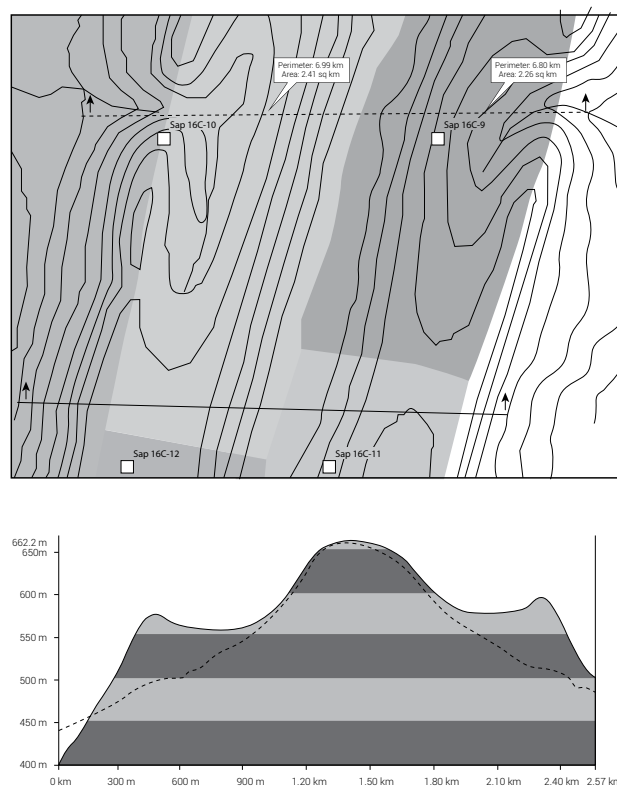


Figure 9. Similar to figure 8, profiles drawn through the saps (dashed line) and through the knob (solid line) where saps occur on both sides of the same ridge at the same elevation suggest formation controlled by elevation rather than formation controlled by underlying structural geology (erosion-resistant strata) (Vertical exaggeration 4:1). (Images derived from Delorme Topo USA 8.0 software, overdrawn by author.)



Figure 10. A small-scale example of a receding tide producing landforms in loose sediment, similar to those observed in Pennsylvania. The pronounced knobs, nearly equally spaced, formed in several hours by a combination of hydraulic sapping and gentle wave action (Lovers Key State Park, west coast of Florida at the Gulf of Mexico). (Photo by author.)



Figure 11. A demonstration of how wave action may be a formative part of the sapping features studied. The deepening sap areas capture the waves diverting energy away from the knobs. The entire cycle only lasts for a fraction of one 6-hour receding tide yet leaves a distinctive landform (Lovers Key State Park, west coast of Florida at the Gulf of Mexico) (Photo by author).

The averaged height where the sap discharges become generally indistinguishable from the surrounding topography was 343.7 m ASL. We calculated this measurement as a possible location where sea level lowering paused—terminating the sapping action. A sea level residing for a time slightly below 343 m ASL would remove the sapped sediments and could also leave traces of a remnant shoreline if not too much time passes (figure 12) (as discussed above, this is a fairly subjective measurement and is not able to be recorded where streams have formed permanent valleys). Part 1 of this paper, published in 2009, calculated a similar change in slope at the bottom of the Eastern Structural front southwest of the Susquehanna River Water Gap (i.e. this study area) of 342.5 m ASL¹⁸ and published two figures showing accumulated scree along a line of this same general elevation at and near the Delaware River Water Gap, further to the east.¹⁹

Conclusion

A distinctive landform repeats hundreds of times in the Appalachian Mountains of Pennsylvania. These landforms are characterised by distinct features postulated to be the result of hydraulic sapping, such as bowl-shaped canyons, no head stream, distinctive profiles, and a narrow range of area-to-width ratios. Careful measurements were analysed to demonstrate the consistency and distinctiveness of the 615 saps studied. Two other distinct features uncovered by this study—aligned sagging in the ridge and distinctive knob formations flanking the discharge throat—may be the result of wave action interacting with sapping action.

The saps formed at high elevations just below or flanking the ridges and are arranged in linear groups. These high elevations (in relation to the

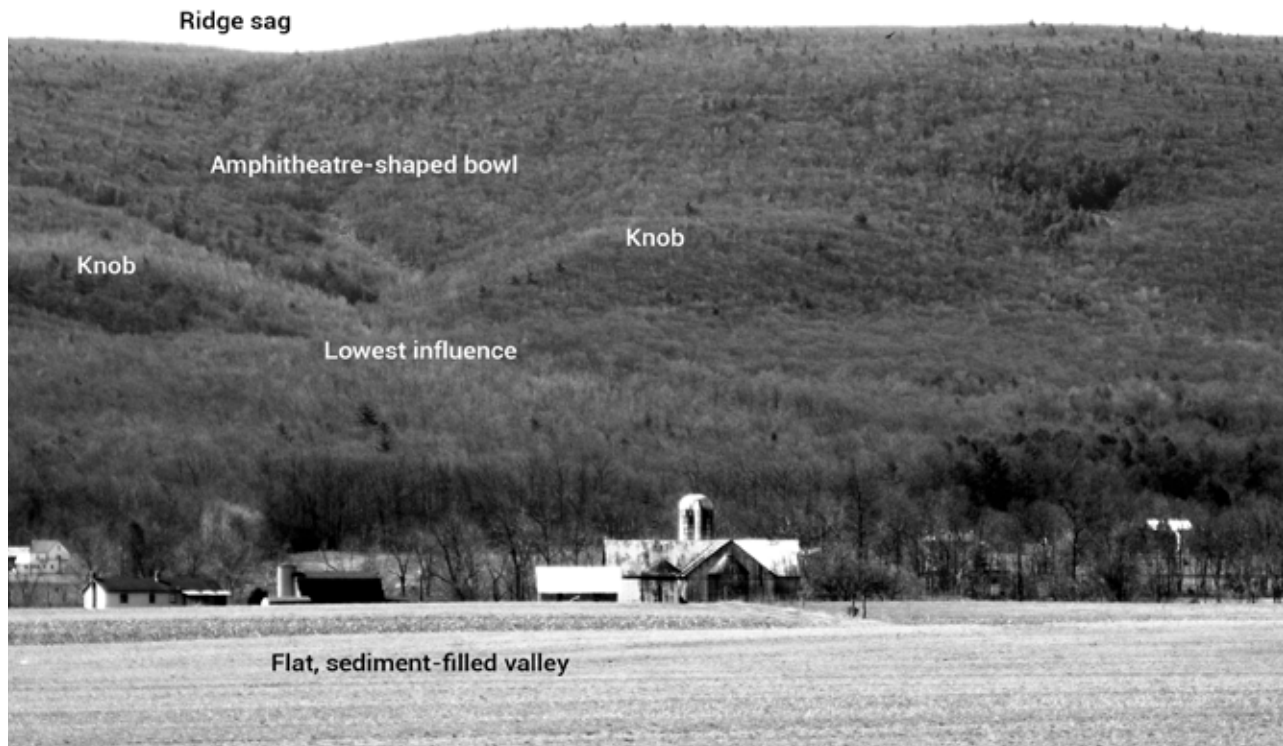


Figure 12. A typical Type 1 sap formation exhibiting knobs on either side of the amphitheatre-shaped bowl below a corresponding sag in the ridge. (Note the farm buildings and silos for scale.) The sap formation ends well above the valley floor with no discharge water course and no accumulated outwash delta or scree. Similar formations repeat regularly to the right and left of the photo at the same elevation parallel to the flat valley floor. A receding inundation could have created the conditions needed for horizontally arranged sap formation and sediment transport (Photo by author).

ridge above) do not provide an adequate ground water reservoir to sustain prolonged sapping, although they may be saturated intermittently.

Slope profiles with benched areas along consistent elevations were associated with many of the saps even though some of the saps are separated by up to 200 km.

The long held teaching that these ridges are remnants of Himalayan-size mountains subjected to millions of years of erosion cannot explain these distinctive and consistent features. High altitude hydraulic sapping can be explained by recession of flood waters from still consolidating sediment after total inundation of the more than 25,000 km² area studied. The fact that the saps have recognisable topographic footprints and profiles is testimony to relatively recent formation; otherwise their distinctiveness would have eroded away.

The recessive stage of the flood, in Genesis 8:1–14, records the scenario that may have produced the high-altitude hydraulic sapping still visible today. The biblical chronology explains the unique conditions needed to form these features in a timeframe of months during a rapidly lowering sea level less than 5,000 years ago.

Definition of terms

- Definitions of terms used in this paper are as below (and illustrated in figure 5):
- Drainage area: the total extent of the current landform that can contribute surface run-off above the throat of the sap, always measured to the ridge.
- Highest influence: the approximate location at the top of the amphitheatre where the contour lines change from a circular pattern to a mostly straight pattern parallel with the ridge.
- Invert: the lowest water-carrying point of any drainage structure at a defined point. In this case, the invert is measured at the lowest elevation of the throat at the point where the section line drawn between knobs crosses the throat.
- Knob: the generally circular area of elevated landmass flanking the throat of Type 1 saps. Water will flow off all sides of a knob, even back toward the hillside. Knobs are indicated by closed circle contour lines.
- Lowest influence: the approximate location below the throat discharge where the 'V'-shaped contour lines (normally indicative of a stream channel) change to generally straight lines.

- No stream: defined by the mapping software with the lack of a solid or dashed blue line.
- Ridge sag: A low point in the ridge above the sap. The ridge line across the top of the sap drainage area must be higher at two locations compared to any point in-between. Multiple sags are included. Ridges that decline in elevation from one side to the other are not considered ridge sag. Some Type 1 saps exhibit exact alignment of the two high-end points of the ridge with the knobs flanking the sap throat.
- Throat: the point of drainage discharge from the bottom of the sap. Most throats are now dry, but may convey an intermittent stream or permanent stream if the sap has a spring or is large enough to collect precipitation.
- Width: the width of the sap as measured from the peak of one knob to the other. In Type 1 saps this measurement is self-defining. In Type 2 saps the width is measured subjectively from the approximate widest point of the drainage area at the low side passing across the throat.
- Bench: a lower sloped area on a higher sloped mountainside suggesting formation by a change in the initial erosion mechanism. Saps were found to form in the benches.
- Group #: an arbitrary number assigned to each group of saps for general identification purposes only. The group numbers are generally arranged in three arcs from southwest to northeast. There is no significance to the 'A', 'B', 'C', etc. after the number.
- High altitude: the relative location of the sap compared to the ridge. For this paper it means the highest areas of influence of the sap amphitheatres are averaging more than 500 m above sea level in ridges averaging 632 m above sea level.
- Intermittent stream: defined by the mapping software with a dashed blue line.
- Sap #: the saps in each group are numbered consecutively, always from southwest to northeast (left to right). Saps in the figures are identified by combining the Group # and the Sap # with a dash, such as 16A-3 (the third sap from the southwest or left in Group 16A).
- Stream: defined by the mapping software with a solid blue line.

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16. Many of the names end with the term 'gap' even though these are not gaps, but saps. Gaps form a cut through the ridge; saps do not, although more than half of the saps were associated with a 'sag' in the adjoining ridge. There are many other true gaps in Pennsylvania also carrying names, but gaps were not mapped in this paper.
17. Karle, K., Young evidences in an ancient landscape: part 1—the Eastern Structural Front of the Appalachian Mountains, *J. Creation* **23**(3):82, 2009.
18. Karle, ref. 17, table 1, p. 77.
19. Karle, ref. 17, figures 2 and 4, p. 78.

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