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Reidentifying Depositional, Solifluction, "String Lobe" Landforms as Erosional, Topographic, Steps & Risers Formed by Paleo-Snowdunes in Pennsylvania, USA

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Abstract: A controversy arises concerning relict, ubiquitous, depositional, solifluction, "string lobe" landforms in the Ridge and Valley province of Pennsylvania, reported by other investigators. A distinguishment is made here by defending an original interpretation of the particular landforms which identified these as snowdune meltwater-eroded depressions formed within colluvium during cold phases of the Pleistocene Epoch. Hence, the landforms are reassessed as "steps & risers" in this study which is jargon associated with nival erosion. The reidentification is warranted in the study because of multiple lines of evidence including: the landforms' detailed geomorphology and sedimentology; the landforms having a highly, unusual, very repetitive, NE-SW orientation; and the landforms incurring a striking, gravity-defying, characteristic of running-water erosion repeatedly occurring irrespective of the steepest part of the general slope. Besides the evidence offered here, the study also gives insight, resolutions and re-confirmations in order to establish absolute identification while differentiating between discussed, periglacial, relict landforms. An agreement is reached however, regarding actual, true solifluction landforms occurring only on slopes that point in a particular, general direction.

Keywords: Snowdune Meltwater-Eroded Depressions, Steps & Risers, Cold Phases of the Pleistocene Epoch, Periglacial, Pennsylvania, USA

1. Introduction

Particular, ubiquitous, relict landforms carved in colluvium originating from snowmelt (nival) erosion during cold phases of the Pleistocene Epoch, occur mostly on south-facing, mountain slopes within the Ridge and Valley province of Pennsylvania (PA), USA, were reported by Marsh [1, 2, 3] and Iannicelli [4] Later, the landforms were reinterpreted by Craul [5] and Merritts et al. [6] as having a solifluction origin while being depositional in nature. So, arguments and a differentiation are made here which will attempt to negate the reinterpretation made by both of the latter authors while re-confirming Marsh [1, 2, 3] and Iannicelli [4].

The Ridge and Valley province in PA is 32,442 km² in area while it's mountains lie within the present-day Temperate Zone. The slope-landforms in the study evolved because of a very harsh, cold paleo-climate that created paleo-permafrost in the terrain along with air-borne, snow-bearing, paleo-winds depositing snow upon the terrain. These paleo-climatic conditions combined to generate certain geodynamics responsible for the evolution of the landforms.

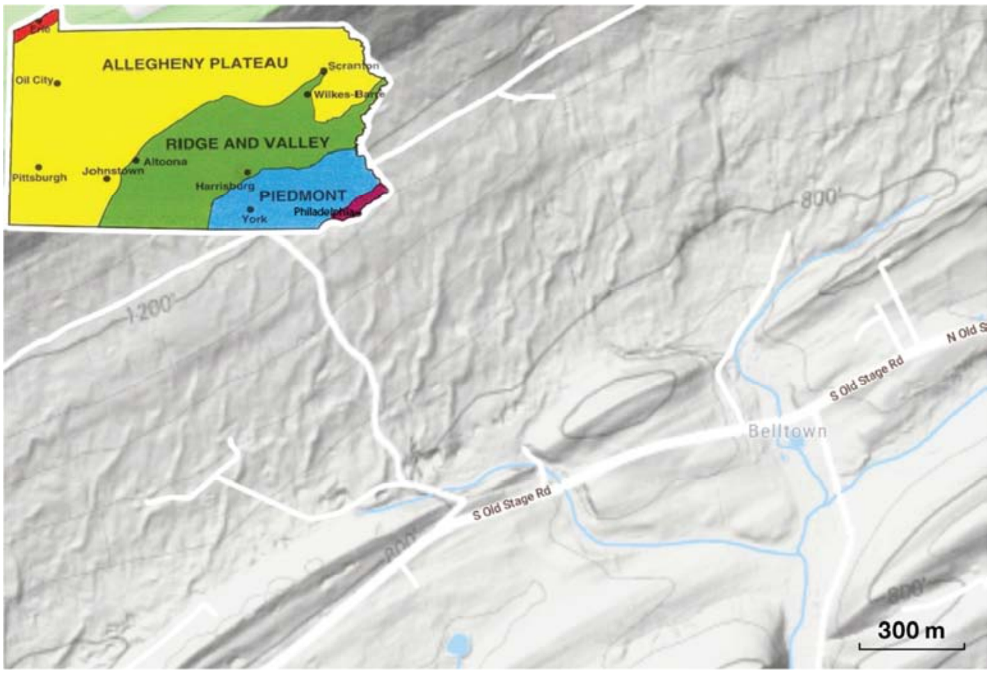
2. Methodology

The thesis of the study is devised by synthesizing many conclusive facts and qualitative data from papers published in peer-reviewed mediums while incorporating analogs and established, geological concepts which absolutely reidentifies the geomorphology of the landforms that are believed to be misinterpreted by other investigators. In addition, field observations and circumstantial evidence are given while reasonable arguments are made along with internal and external comparisons of the landforms. The analyzed landforms are relict and hence inactive, which then limits quantitative data, other than size-dimensions since activity-measurements cannot be generated.

3. Discussion

3.1. Topographic Steps & Risers

The controversial landforms were originally concluded to be relict, erosional-topographic, steps & risers formed by erosive meltwater from transverse paleo-snowdunes during cold (periglacial) phases of the Pleistocene Epoch [1 - 4] (Figure 1). These particular landforms are extremely ubiquitous, occurring mostly on south-facing, mountain-slopes within the Ridge and Valley province of Pennsylvania, USA, south of the Wisconsinan glacial limit. A detailed description of the steps & risers includes a very consistent, oblique-to-the-general slope, NE-SW orientation while their dimensions are commonly both short-measured and lengthy. The depressions (the steps) each end at a complementary, downhill riser. Conversely, Craul [5] (Figure 2) indicated a depositional origin since he described the risers as relict, sinuous, elongated, colluvial, “strings” of solifluction on a south-facing, general slope in a study site at Tussey Mountain, PA. Likewise, Merritts et al. [6] reported and illustrated the same type of so-called solifluction landforms that appear on south-facing slopes of the mountains in the Ridge and Valley province of PA.



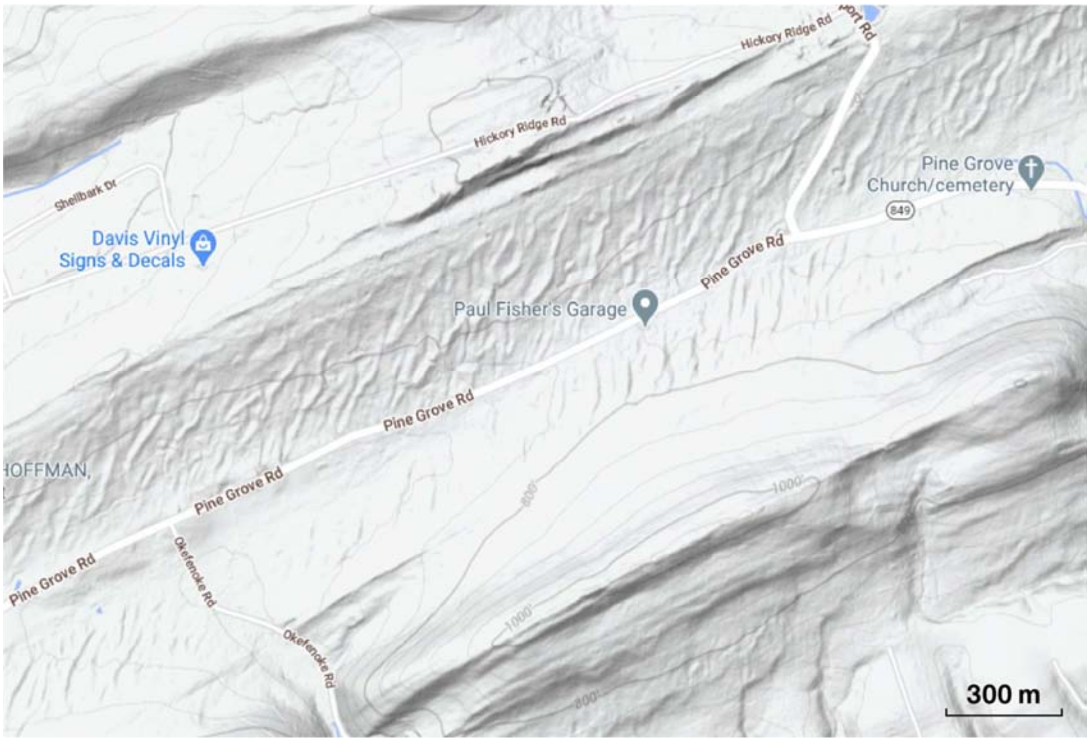


Figure 1. *Examples of Google Terrain maps that exhibit ubiquitous, NE-SW oriented, oblique-to-the-general slope, landforms that lie repeatedly and consistently across colluvial deposits typically on south-facing, general slopes of mountainsides encompassed by the Ridge and Valley province of Pennsylvania (PA). From top to bottom, locations are: (a) Belltown, PA, near Old Stage Road at 40° 43' 00.90" N, 77° 24' 52.48 W; (b) Montgomery, PA, near State Home Road at 41° 09' 42.15" N, 76° 51' 42.96" W; (c) New Bloomfield, PA, near Pine Grove Road at 40° 25'11.26" N, 77° 11' 13.94" W. North is towards the top. Courtesy of Google Maps.*

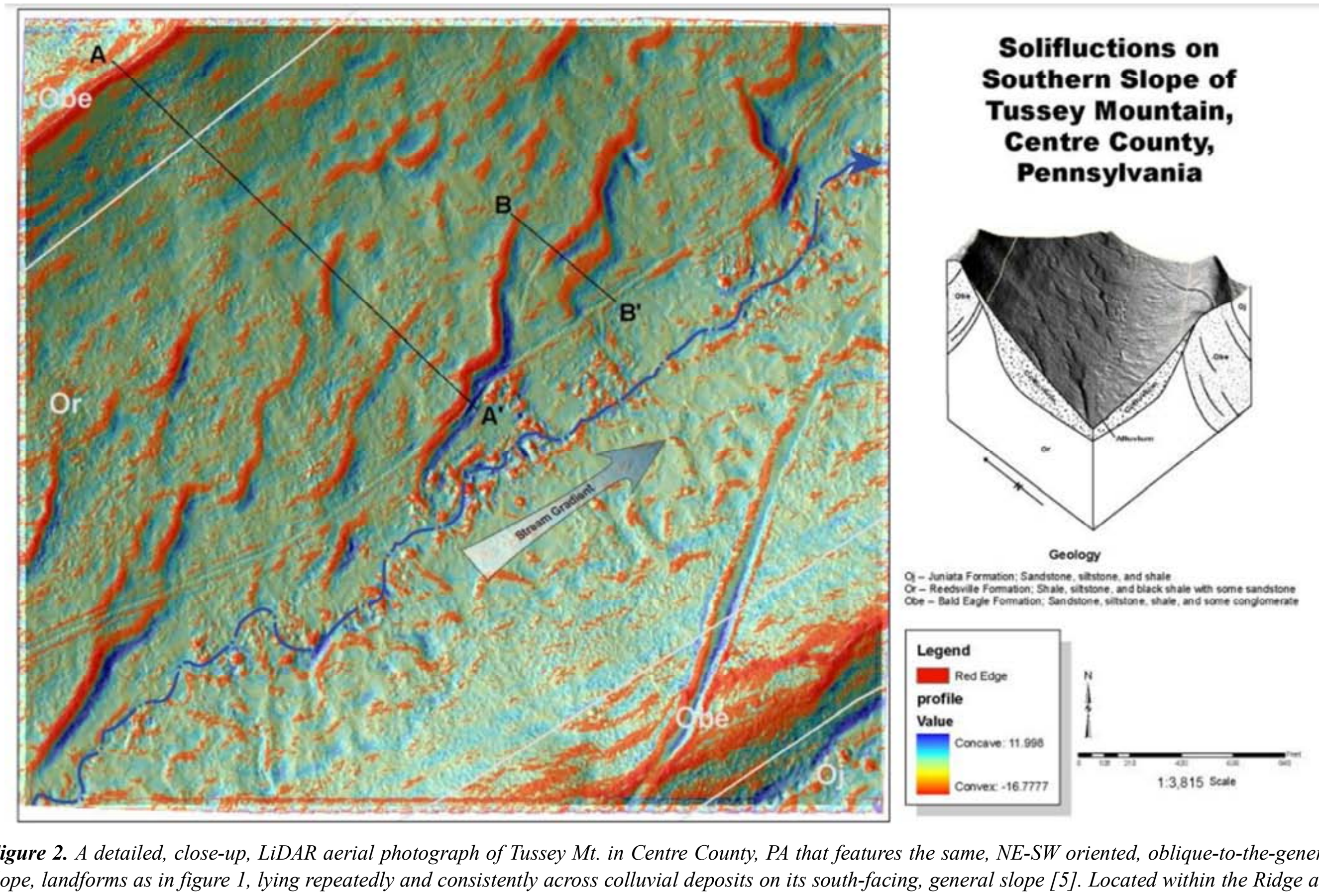


Figure 2. *A detailed, close-up, LiDAR aerial photograph of Tussey Mt. in Centre County, PA that features the same, NE-SW oriented, oblique-to-the-general slope, landforms as in figure 1, lying repeatedly and consistently across colluvial deposits on its south-facing, general slope [5]. Located within the Ridge and Valley province of PA. Courtesy of NRCS.*

Evidence indicating an erosional origin is by comparing the controversial landforms to Pleistocene periglaciated mountainsides which feature consistently oriented, oblique-to-the-slope, elongated depressions adjacent to their complementary, consistently oriented, oblique-to-the-slope, elongated risers, altogether formed by wind-drifted snowdunes and their consequential, erosional snowmelt [4] (Figure 3). The developmental mechanics are diagrammed which includes showing how gravity-defying, snowmelt from a snowdune, erodes repeatedly irrespective of the steepest part of the general slope [4] (Figure 4).

Figure 3. *Aerial photograph showing modern-day, mountainsides dissected by snowdune-snowmelt erosion which display the steps & risers characteristic. These were created when the snowdunes-themselves were formed by the snow-bearing, paleo-wind when it dropped its own airborne snow. Note the oblique-to-the-general slope, snowmelt-carved valleys that are oriented transversely to the paleo-wind coming from a certain direction, Modern snowbanks now occupy the largely-inactive landforms. Length of an individual snowdune is ca. 100 m. R = riser, D = divide. Dashed-line symbols are emplaced close to the axis of the central valley-bottoms. Location is the Northern Sweetwater Mountains between the states of CA and NV [4]. Photograph courtesy of John Dohrenwend.*

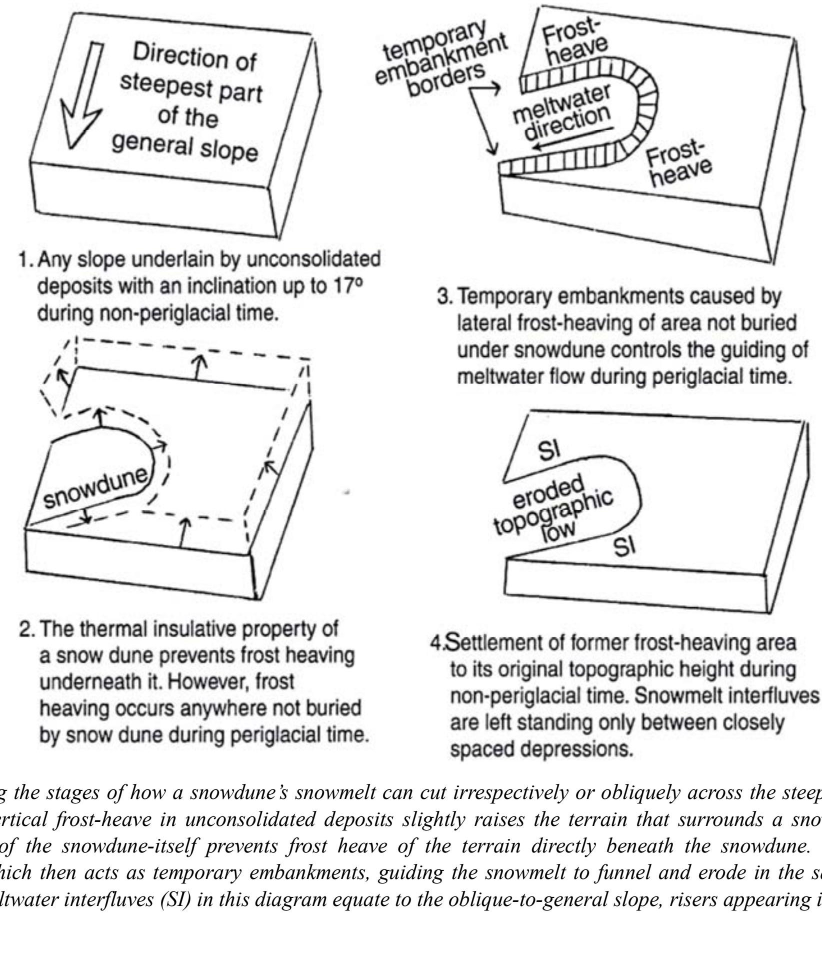


Figure 4. *Diagram explaining the stages of how a snowdune's snowmelt can cut irrespectively or obliquely across the steepest direction of a general slope. Due to cold temperatures, vertical frost-heave in unconsolidated deposits slightly raises the terrain that surrounds a snowdune while simultaneously the thermal insulation property of the snowdune-itself prevents frost heave of the terrain directly beneath the snowdune. This slightly raised the terrain surrounding the snowdune which then acts as temporary embankments, guiding the snowmelt to funnel and erode in the same direction of the snowdune's orientation [4]. Snowdune meltwater interfluves (SI) in this diagram equate to the oblique-to-general slope, risers appearing in figure 3.*

Further evidence of the steps & risers being formed by transverse, paleo-snowdunes, is where the Ridge and Valley province in PA structurally transitions from a NE-SW orientation to virtually a N-S orientation as it nears the border between PA and MD because the landforms visually fade out at that point. This is coincidently due to the latter orientation of the Ridge and Valley mountains no longer being transverse to the snow-bearing paleo-wind that blew from out of the NW and towards the SE [1, 2, 3]. Corroborating the origin of the above-periglacial landforms are many, related, similar, Pleistocene, micro-scale to meso-scale, geomorphic forms in the Midwest of the USA [7, 8]. Those landforms of the Midwest take on a greater significance and a much, broader application since many contiguous regions there were physically dissected by meltwater erosion from transverse snowdunes.

Simple field observations argue against a solifluction origin since many, multiple sets of individual risers measure up to a ½ km long in width while widths of fronts of inactive and active solifluction lobes typically do not approach that same measurement.

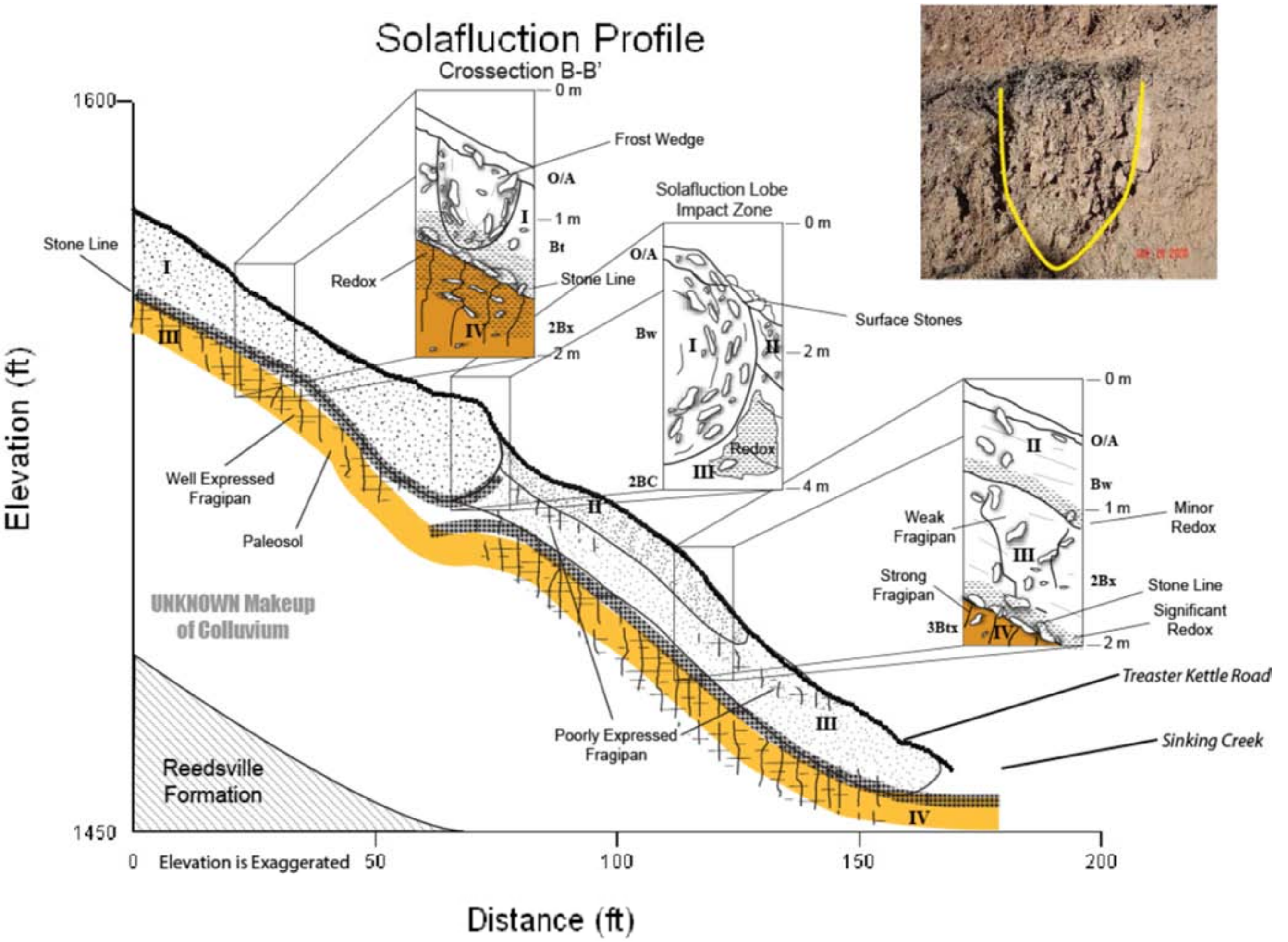


Figure 5. A longitudinal profile along B – B' (see figure 2) of a flank on Tussey Mt. It exhibits sediment-bed " I " consisting of mostly fine clasts and an upward curvature of very coarse clasts piled up on top of one another within the tail-end of sediment-bed " I " noted in the Solifluction Lobe Impact Zone [5]. Courtesy of NRSC.

3.2. An Additional Feature Attached to the Riser Called a "Pronival Rampart"

Craul's [5] longitudinal, profile and internal structure (Figure 5) prompted him to conclude that the landforms are relict, "string-lobes" of solifluction origin. Solifluction lobes are slow, mass-movement landforms on mountainsides which then classifies them as completely constructional in nature. In contrast, the study's assertion of snowmelt from perennial, paleo-snowdunes gradually eroding the ground beneath the snowdunes creating the previously-mentioned, depressions upslope from the risers, then categorizes these as largely destructional topography in addition to these being partly depositional in nature because of large clasts piled upwards at their downhill, tail-end contained by the riser (see sediment-bed " I " and "Solifluction Lobe Impact Zone" in Figure 5). A key observation here of the piled-up, large clasts actually displays a curving-upwards trend in Figure 5. The study correlates the tail-end, curving-upward trend of these piled-up, large clasts to either a protalus rampart or pronival rampart type of landform [9, 10] (Figure 6) while appropriately choosing the term "pronival rampart" here.

The sequential evolution of it starts with the talus (large clasts) originating from far upslope at the summit-face of Tussey Mt. where exposure of the bedrock summit-face experienced paleoclimatic, freeze-thaw weathering and consequent frost-shattering during cold phases and permafrost conditions of the Pleistocene. Then, weathered-derived rubble (talus) from the summit-face, fell onto the surface of a snowbank or snowdune, followed by downslope-sliding of these large clasts, in which case, the snowpack had already hardened through thickening and compression (firn), preventing any gradual sinking of the large, heavy clasts down to the base of the snowdune. Continued, sliding of the large clasts moved these to their final resting point, which was the growing-rampart downslope. Figure 7 [11] permits manifestation of the genesis of the previously-mentioned, curving-upwards trend of the downslope, piled-up, large clasts (Figure 5): here, snowbed #1 in the diagram builds up its own pronival rampart followed by a second generation of a snowbed (snowbed #2) that incurred a 2nd rampart, partly superimposing it over the 1st rampart. In this same diagram, the occupied space between where the contact of both ramparts diverge away from one another is angular while similar in shape to a " > " symbol. This type of stratigraphic relationship roughly resembles the upward curvature of the piled-up, large clasts located within the tail-end of sediment-bed "I" in Figure 5. The sequential process ends after final melting of both snowbeds leaves the dual rampart standing (Figure 7) while sediment from far upslope gravitated downhill and descended to the dual ramparts in combination with "let-down" material that was superimposed over the surface of the melting snowbeds. Evidence for a former snowbed #1 associated with Figure 7, is the recognition of a "step" or terrace eroded in the paleosol within zone III of Figure 5 by a melting-snowbank or nivation, popularly known as a cryoplanation step or terrace. Jargon for the particular, discussed sediment-beds diverging away from one another in rampart #2 superimposed over rampart #1 is lacking, while the only other stratigraphic resemblance to it in the literature is termed a "pinch-out". But however, pinch-outs are only associated with marine, stratigraphic contacts that diverge away from one another [12], unlike the terrestrial situation here, which makes it probably irrelevant, and hence, disjointed to the discussion of pronival ramparts. The pronival-rampart landform in general, also explains the observation of a landform downhill from a tread / depression described as a semicircular, blocky barrier found at a step & riser in PA, reported by Marsh [1].

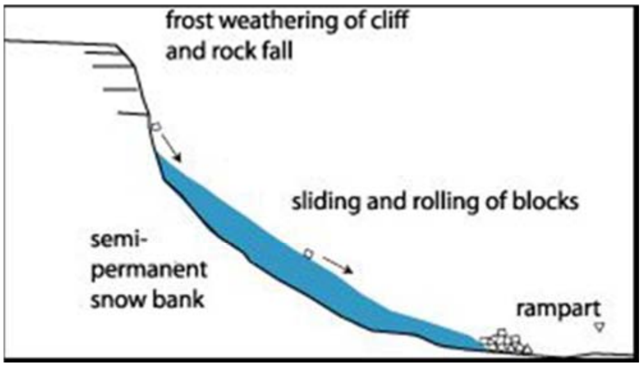


Figure 6. A longitudinal profile of a typical, protalus rampart or pronival rampart in the process of being built. It begins when bare bedrock at the summit-face experiences frost-shattering which produces talus falling upon the surface of a snowbank where the talus then slides downhill, ultimately creating a rampart at the downhill-end of the snowbank. Creative Commons attribute 3.0.

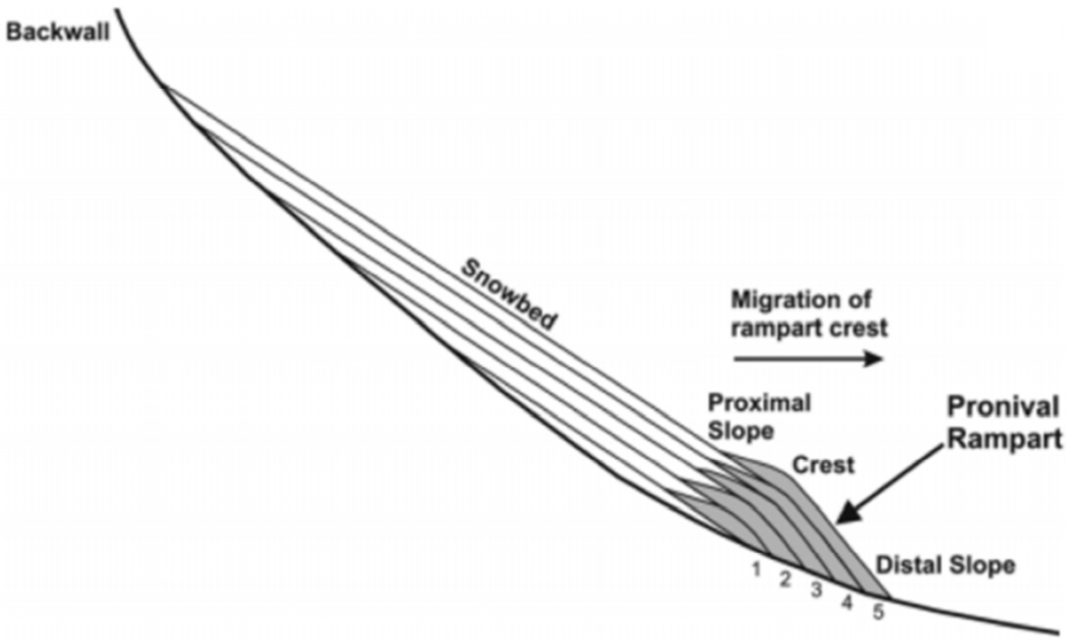


Figure 7. Diagrammatic, up-close look at the stacking of downhill-pronival ramparts upon one another that are associated with the generations of snowbeds or snowbanks [11]. The key observation here is where the contact between protalus rampart #1and protalus rampart #2 diverge away from one another which gives it a " > " shape in the illustration. The lines in the preceding symbol represent each protalus rampart diverging away from one another which alludes to a rough shape of an upwards-curvature of the rocky structure seen within sediment-bed "I" in figure 5. Permission to duplicate granted by John Wiley & Sons / License No. 5022651410242.

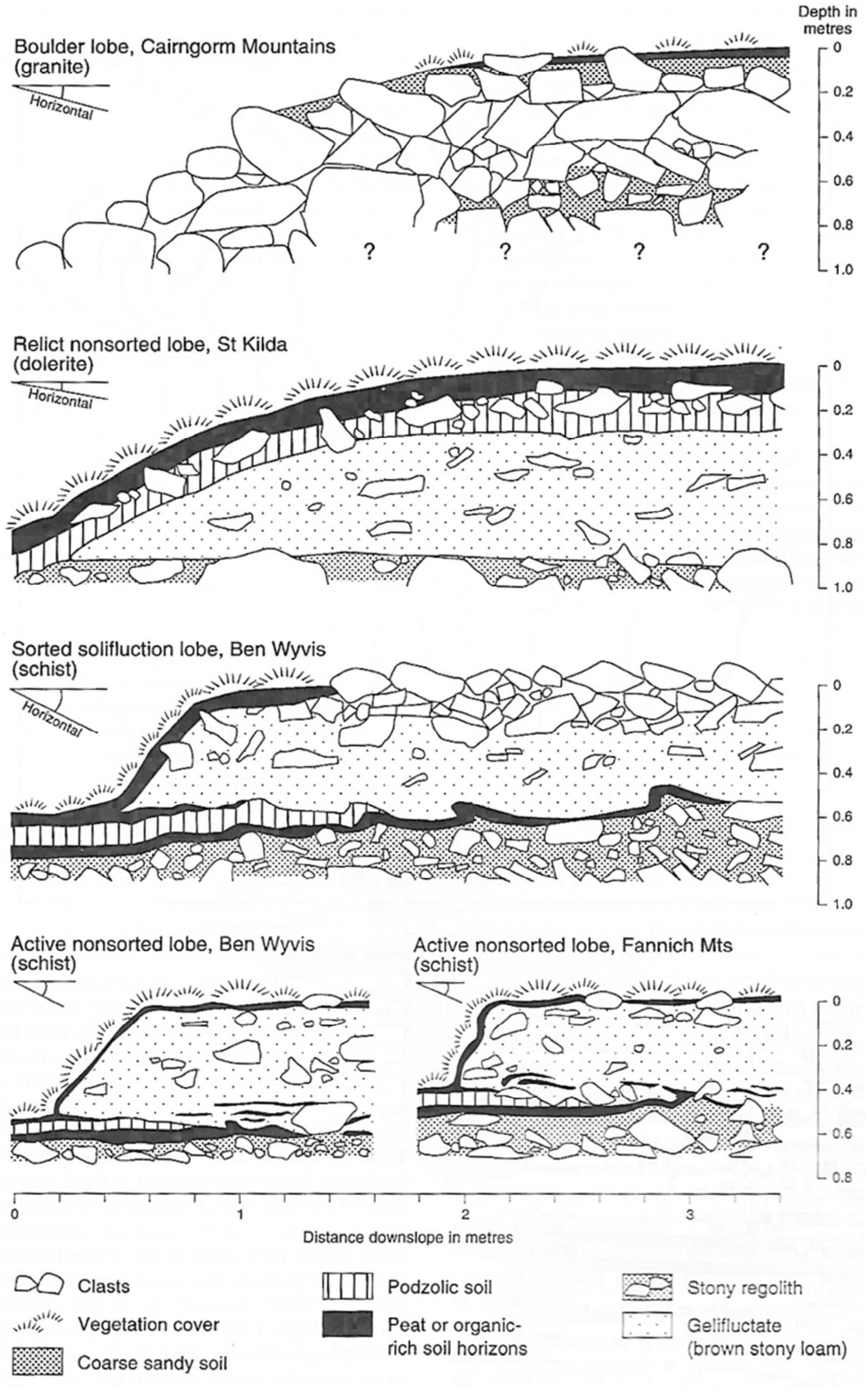


Figure 8. *A diagrammatic survey of solifluction lobes which are located very far spatially from one another, encompassed by the highlands of Scotland [13]. Permission to duplicate granted by Cambridge University Press / ID No. 48169.*

3.3. Actual, True, Solifluction Landforms on the Opposite, North-facing Slope Adjacent to Tussey Mountain

Further evidence nullifying the questionable landforms interpreted as solifluction string-lobes, is when we compare longitudinal and internal profiles of surveyed, true, solifluction lobes found in the highlands of Scotland such as Ballantyne & Harris [13] (Figure 8). Here, all of the illustrated, typical, solifluction lobes do not contain a solitary, curvature of only large clasts at their noses. But it's worth briefly discussing here, one of those diagrammatic, solifluction lobes, which is, the active, nonsorted, solifluction lobe of the Fannich Mts in Figure 8. This is because of a slight, vague resemblance of a layer of large clasts encasing this particular active solifluction lobe may be slightly compared to the curvature of piled-up, large clasts concentrated only at the nose of the relict, solifluction landform on Tussey Mt.in PA,, seen in Figure 5's "Solifluction lobe impact zone". But again, differences here between the two types of landforms, are that the Fannich Mts., solifluction lobe seems to be completely surrounded by a continual layer of large clasts from top (surface of the lobe) to bottom (underneath the lobe). This may be explained in sequence first by frost-shattering of an upslope, bedrock, summit-face on these mountains that dropped its talus upon the surface of this particular, active, solifluction lobe followed by the talus gravitating downslope all along the surface of the lobe including the nose of it. The diagrammatic, basal, large clasts of this same active solifluction lobe are popularly referred to as a "stoneline" (also seen in Figure 5), which is simply a running-water (or snowmelt) lag of coarse clasts while it has no relationship to the formation of any solifluction lobe. Anyway, so the difference between the active solifluction lobe in the Fannich Mts. (Figure 8) vs. the relict, so-called, solifluction lobe of Craul [5] is the curvature of piled-up, large clasts (seen in Figure 5) happens to have a gap between it and the top surficial layer of large clasts belonging to this relict solifluction lobe. This is versus the surficial layer of large clasts that is continued without any gaps protracting or extending to the large clasts of its nose belonging to the active solifluction lobe in the Fannich Mts (Figure 8). The only other typical, solifluction lobe in the literature that is comparable to the sedimentology of Craul [5] is called a "stone-banked lobe" [14, 15]. But however, this type is very dissimilar in size, measuring up to only 30 m versus the landforms discussed in the study, which measure up to ½ km in width as mentioned earlier. Besides, the landforms' consistent occurrence obliquely across the general slope also rules against a solifluction origin.

The study does agree with Craul [5] (Figure 2) and Merritts et al. [6] about the existence of actual, true, relict, solifluction-landforms appearing only on north-facing general slopes of the mountains in the Ridge and Valley province of PA. Indicators of this interpretation include the fact of individual, U-shaped & crescent-shaped, relict, solifluction-lobes always pointing downhill along the steepest part of the general slope, causing their noses to occur normal (perpendicular) to the axis of the valley-bottom stream (Sinking Creek) as in Figure 2. Thus, differentiating an origin between true, relict solifluction lobes of Craul [5] and Merritts et al. [6] on north-facing general slopes versus the other consistently, NE-SW oriented, oblique-to-the-general slope, erosional steps & risers on south-facing slopes, is made here while the lines of evidence re-confirm the original identification of the erosional, step & riser landforms made by Marsh [1, 2, 3] and Iannicelli [4].

3.4. Slope Direction as an Important Factor in the Generation of All Landforms in the Study

A popular concept that may explain why different landforms formed, involves the direction in which the general slopes faced. Snowdunes and ordinary snowbanks are promoted on lee-side, general slopes of mountains which in this case, are the south-facing, general slopes in the Ridge and Valley province of Pennsylvania. The dominant, snow-bearing, paleo-wind blew in the SE-direction of this province [1, 2, 3] while emplacing its wind-blown deposit of snow upon the lee-side of mountains which then subsequently incurred erosive snowmelt to carve out the steps & risers that appear on south-facing, general slopes. This occurred while the windward-side, north-facing general slope, was wind swept when freshly, laid-down, deposits of snow, started wind-drifting up to the summit, ultimately leaving those north-facing, general slopes, mostly bare of snow. Here, a lack of an insulating-snow cover on north-facing general slopes then progresses the evolvement of solifluction lobes since these are dynamically frost-dependent, viscous masses of sediment and soil which slowly gravitate downhill. In addition, the north-facing general slopes simultaneously incurred only a small amount of solar heat from the sun during winter which then facilitated paleo-frost. That contrasts with, let's say, a sun-heated, general slope which would melt and fluidize any permafrost foundation on a mountainside in causing rapid mass movements such as landslides or saturated debris flows.

4. Conclusion

Relict landforms interpreted as having only a solifluction origin by Craul [5] and Merritts et al., [6] are re-identified here as snowdune-meltwater, erosional depressions while their downhill, tail-ends feature a pronival rampart which is depositional in nature. These particular two-part or hybrid landforms called "steps & risers" mostly occur on south-facing, general slopes of mountains in the Ridge and Valley province of PA. They also contrast against actual, true, relict, solifluction landforms that occur on north-facing general slopes of the mountainsides within the same structural province.

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