Soil profiles of grasslands on Mt. Fuji’s northern side

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Introduction:

For thousands of years, Mt. Fuji’s skirt has been the ground for numerous volcanic events including pyroclastic flows, lava flows, and tephra explosions. These events have helped generate a biodiverse environment and a home for many organisms, human and non-human alike. In our research, we examined three different grasslands around the north face of Mt. Fuji: the Motosukōgen, the Nashigahara, and the Nojirisōgen grasslands. Each grassland can be characterized by the lava flows and other disturbances that have defined their soil composition, topography and humic content.

Lava flows inhibit plant growth due to the thickness and porousness of the flow. The thick, hard lava rock does not weather easily, and the porousness allows water to percolate out of reach of plant roots. According to Deligne et al (2012), plant growth can still be achieved on lava flows despite these obstacles, however, this is only possible after weathering and the deposition of externally derived material. Deposits from historic land use patterns (i.e., prescribed burns and mowing) and events such as mudflows and *yukishiro* (slush flows) introduce foreign material onto the lava flows. These foreign materials cause the grasslands to differ in their overall soil profile despite the commonalities in relative geography and climate between the regions. In this study, we look into how lava flow age, deposits from external sources, and land use affect soil depth and composition.

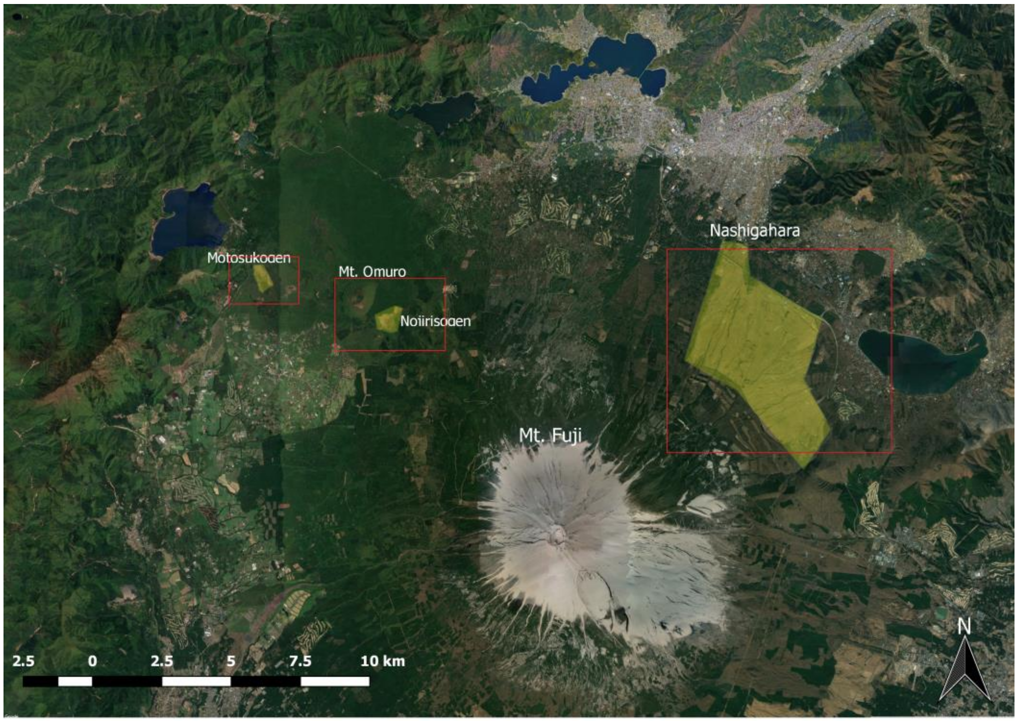

Figure 1. Overview map of Fuji-Hakone National Park land with insets of Figures 2, 4, and 6 shown. Grasslands are highlighted in yellow.

Geologic and Land Use History:

The three grasslands we examined, Motosukōgen, Nashigahara and Nojirisōgen, all have a detailed topography and history of land use. Motosukōgen, located northwest of Mt. Fuji, contains the oldest lava layer of the three grasslands, which flowed sometime between 15,000 and 6,000 BCE. We noticed during our research that the land in the Motosukōgen varies in topography. For example, we took samples on a slope, on flat ground and on a swell. In addition, plant succession in the Motosukōgen has been greatly expedited by weathering and tephra deposits due to its age. This grassland, unlike Nojirisōgen, is regularly mowed and burned by the local village exercising its *iriai* rights.[1] However, since grass is no longer needed for thatched roofs, the grassland has declined in size due to decreased maintenance and forest expansion.

Nashigahara, the largest of the three grasslands, is located to the northeast of Mt. Fuji. Nashigahara's lower layers contain material from *yukishiro*. Covering the *yukishiro* debris layer are two lava flows that occurred around 1000 years ago, the Hinokimarubi and the Takamarubi. Within the last few hundred years, the Hinokimarubi and the Takamarubi funneled *yukishiro* into the troughs between the two flows. Because of this, plant growth is noticeably more abundant in these area. Since the early 20th century, this grassland has been a practice range for the Japanese military. From 1952 until present day, the Nashigahara has been used by the Self Defense Force during and after the SCAP (Supreme Commander of the Allied Powers) occupation of Japan. Regarding management of the grassland, *iriai* rights have been under debate between the Self Defense Force and the neighboring villages. Currently, locals are only permitted access to the Nashigahara on Sundays and holidays, while guests need permission to enter the space.

Nojirisōgen, the smallest of the three grasslands, is located to the northwest of Mt. Fuji and southeast of Mt. Omuro. Because of its close proximity to the Omuro cinder cone, scoria from a 3500 to 2900 year old eruption is present in the soil (Takada et al, 2007). This grassland dates back to a period called the Undivided Subashiri B stage which occurred between 3600 and 1500 BCE. In addition, because the grassland has been largely unmanaged since 1962, forest has begun to encroach on the grassland, shrinking its size. Within the last three years, however, the local village has resumed exercising their *iriai* rights by cutting trees for timber and burning the grass to slow forest growth.

Methodology:

In the three grasslands, we dug holes to see how the different regions varied in soil composition. Because geomorphic disturbances support plant growth (Deligne et al, 2012), we decided to look for indicators of such disturbances and their possible effects on soil depth and plant succession. Using knowledge about the geologic history of the areas we surveyed, we could make deductions about how different processes on these lava flow areas have shaped

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[1] *Iriai* rights are concerned with communal use and are usually negotiated among two or more parties, usually between owners and users. These rules are often binding, entailing how the land should be used and how often it should be used to remain community land. As part of exercising *iriai* rights, many villages have historically burned the grass to make the ground more suitable for farming, harvested herbs and used the grass for thatched roofs (Bernstein, 2013). In this study, whether or not these behaviors are practiced regularly to present day may contribute to our results.

the current landscape. To assess these factors in the grasslands, we decided to identify key characteristics of soil horizons such as the primary and secondary textures, amount of organic material, grain size and Munsell color.

First, to record data on our iPads during fieldwork, we designed a survey using an app called Fulcrum to detail important elements for each soil horizon. Fulcrum attaches survey data to GPS locations and records the data online so that it can be downloaded as shapefiles, XLXS files, and other useful file types. The applicable fields we added to the survey were grassland name, backup GPS coordinates, depth to the bottom of the horizon, primary texture, secondary texture, organic content (none, sparse, moderate or abundant), Munsell color, general notes and observations, location relative to lava flows, and the topographic location (swell, dip, slope and flat). A survey was completed for each soil horizon at any given plot location.

The general area where we dug our holes in each grassland was determined by field ecologist and research supervisor Watanabe Michihito. He would bring us to a region he thought was applicable to the research that day, and another research group with a focus on plants would determine the plot boundaries, marking a square with 10 m sides. We began our excavation as close to the center of each plot as possible. In a few plots, we had to move our digging site by as much as a meter in order to avoid damaging endangered plants. Once we had found a place to dig, the iPad's internal GPS automatically mapped our plot points in Fulcrum, but we also used a separate GPS tracker to manually record backup coordinates in the survey to control for device errors observed in previous surveys.

To dig each plot, we used a closed-sleeve auger to bore a hole in the ground and a garden knife to remove rocks that impeded our digging progress. For measurements, we used a one-meter stake and a 50 meter measuring tape to find the depth of each plot in centimeters. To identify texture, we primarily performed a tactile examination of wet soil and occasionally used a 10x loupe magnifying glass to identify the primary and secondary materials of the soil (clay, silt, sand or gravel). Because the color of the soil was important to determine its composition and history, we used the Munsell color book to identify each horizon.

Finally, for our visuals, we used QGIS to create maps of the grasslands with our Fulcrum data points with symbols which varied visually in size to reflect the depth of the hole. The colors were edited in Microsoft Paint to illustrate the number of horizons in each sampled plot and also to create the red inset boxes on our inset map. We used Adobe Photoshop CC to create soil columns that represent each horizon's Munsell color, predominant texture, and layer depth to scale.

Results:

During our data collection we paid particular attention to the number of soil horizons and the soil composition. In all the plots we dug in the Motosukōgen, an abundance of organic material was found, especially a root mat within the first few centimeters of the surface. Regarding primary texture, the plots contained mostly sand of varying coarseness. Medium to large size rocks from about 5-11 cm in diameter began appearing as well from around 40 to 50 cm. However, one disclaimer to this consistency should be noted: each of the sampled plots was geographically close, meaning that each site was likely affected similarly by any external processes.

Examining specifics, in our first plot at Motosukōgen, we found a total of three soil horizons. In Figure 3, our first plot's shallowest soil horizon went to a depth of 16 cm. It was a black hue comprised primarily of sand and secondarily of silt. The second soil horizon in Plot 1 went to a depth of 35 cm and lightened in color. However, after 41 cm, large lava rocks started appearing and we could not go further. Plot 2 contained a total of five soil horizons, the first containing a mat of organic material for a depth of 9 cm. As we dug deeper, the Munsell color began to lighten until we were stopped at 57 cm by large rocks. For the most part, the second plot contained primarily sand and silt with a small amount of clay. We noticed an odd increase in organic material around 49 cm down (to be expanded on in the discussion). Plot 3 contained two soil horizons, reaching a depth of 53 cm, again containing primarily sand and silt.

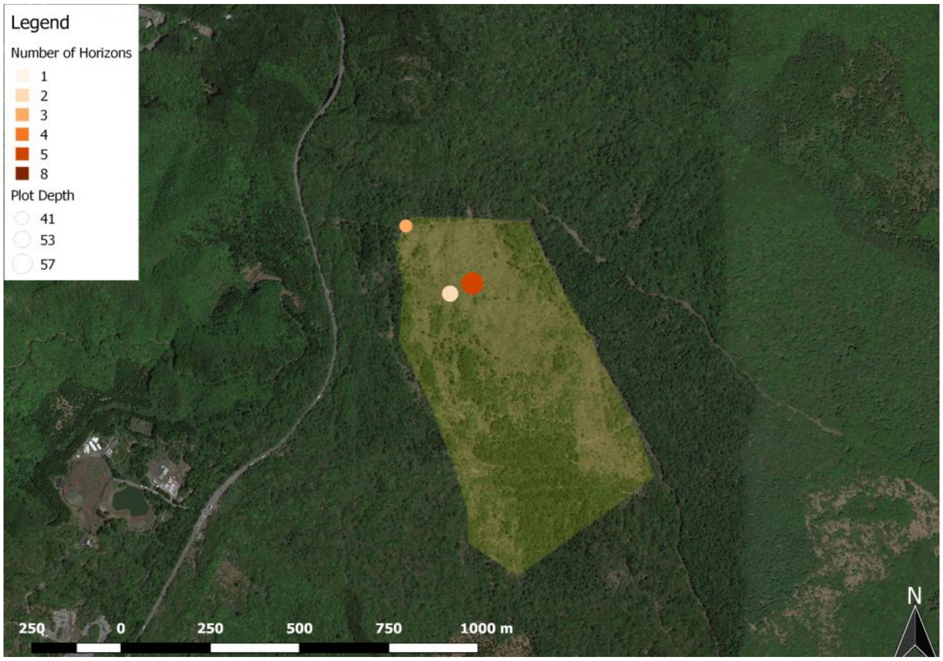

Figure 2. Motosukogen grassland highlighted. Number of dots indicates plots dug, dot size indicates depth of hole and color indicates number of soil horizons.

Figure 3. Soil columns from the Motosukōgen field. Plot number, depth (cm) and Munsell color are listed. A soil texture legend is also present for reference.

In the Nashigahara grassland we sampled a total of five plots, all of which were dug either between flows or on top of the Hinokimarubi or Takamarubi lava flows. All of our soil samples contained a primary texture of either sand or occasionally gravel, but no consistent pattern of secondary textures could be found. One thing that did stand out to us in all of our Nashigahara samples was the consistently high concentration of organic material in the top layers of our plots. In Plot 1 (Figure 5), the deepest of our five samples ended at 140 cm, and we recorded that black scoria gravel up to 3 cm in diameter began to appear. We noticed that in our plots dug between flows we were able to dig much deeper than ones dug located on flows due to how close to the surface the rocky layers were. Many of our samples have large variation in depth and number of soil horizons. For example, we can attribute the shallowness and low number of soil horizons in Plots 3, 4 and 5 to the lava layer below. For instance, Plots 3, 4 and 5 only contained two layers and the total depths ranged from 15-25 cm because our samples were taken close to the surface of the lava flows.

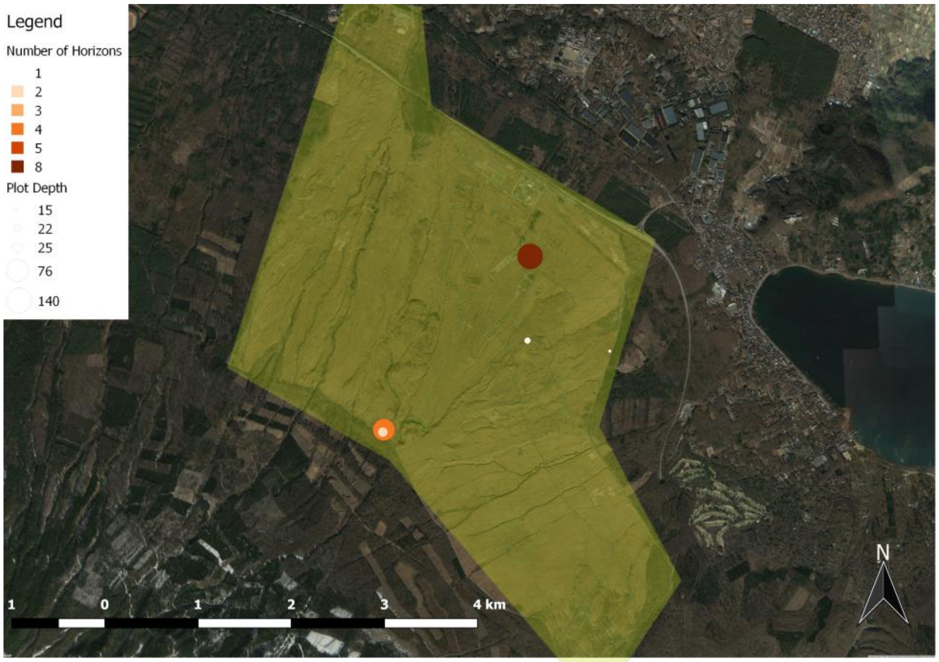

Figure 4: Nashigahara grassland highlighted. Number of dots indicates plots dug, dot size indicates depth of hole and color indicates number of soil horizons.

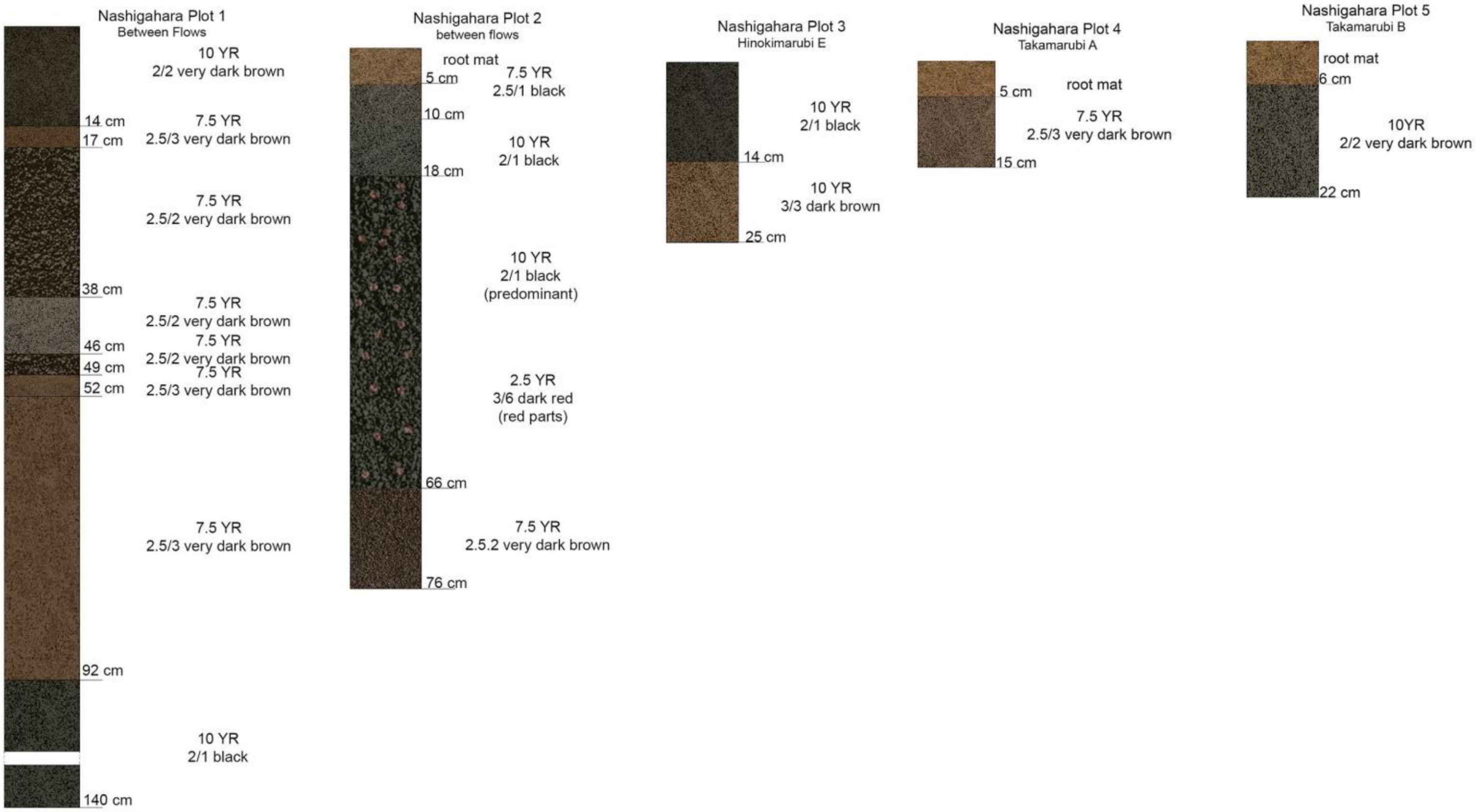

Figure 5. Soil columns from Nashigahara grassland.

Lastly, in Nojirisōgen, we dug one plot and stopped before reaching parent rock due to time constraints and insufficient auger extensions to excavate further. As seen in Figure 7, the plot began with two layers of silt, a layer of gravel, a few layers of sand, and then a 110 cm layer of predominantly black scoria. We believe the thick layer of scoria comes from a previous eruption of Mt. Omuro which last erupted 3500 to 2900 years ago (Takada et al, 2007). Although there were five soil horizons, the one most notable was the fifth one which contained large concentrations of black scoria with some red scoria interspersed between it. The deeper we dug, however, the less red scoria we found. In addition, the deeper we got, the slower the digging became due to the collapsing walls of the hole, resulting in more material to excavate. In addition, because the gravel was so loose, it frequently fell out of the auger as we tried to extract it from underground, which also slowed the pace of excavation.

Figure 6. Nojirisōgen grassland highlighted. Number of dots indicates plots dug, dot size indicates depth of hole and color indicates number of soil horizons.

Figure 7. Soil column from the Nojirisōgen.

Discussion:

Because the Motosukōgen has the oldest underlying lava flow out of the grasslands we surveyed, it has had the most opportunity for weathering and deposits by external forces over time. Despite this, significantly deeper soil profiles were dug at both of the other grasslands; therefore we know that age and soil depth cannot be directly correlated. No significant amounts of tephra were observed, and organic material was found throughout most of the soil horizons. Because the grassland is adjacent to a range of non-volcanic mountains, it is possible that softer rock was eroded from the mountains and deposited on the grassland. It is also possible that pioneer plant species as well as physical and chemical weathering built up these soil profiles over many thousands of years, but given the hard surface of lava flows, it is more likely that erosion or some type of debris flow deposited soil, organic material, and other debris onto the lava flow. Organic material was categorized as either “abundant” or “moderate” for the entire soil profile of Plots 1 and 3, which supports the theory that human management and external deposits encouraged plant succession. The second plot in Motosukōgen had sparse organic material between 30 and 57 cm, but then there was a brief increase in organic material; we hypothesize that this may have been the beginnings of plant succession on top of the lava flow that were buried by a debris flow that brought sand and clay, which observed in higher horizons.

On the Nashigahara, we observed significant variance in soil depth and content. Some plots contained scoria, while others revealed large, dense gravel which was likely broken off of the underlying lava flow. Variation could be due to the significantly greater size of the Nashigahara compared to the other grasslands, which allowed us to sample from more geographically distant and diverse plots. Some plots were on top of lava flows, and others were situated between lava flows, which we believe contributed to the total depth of our samples. The differing geology within a climatically similar area provides data valuable for comparison. Despite these differences, organic material seemed very prominent in the thick upper layers of each sampled plot. Parts of the Nashigahara are significantly closer to Mt. Fuji than the Nojirisōgen and the Motosukōgen, potentially making it more susceptible to *yukishiro*. The Nashigahara has also been historically carefully managed by humans by burning and mowing, and it is more heavily managed today than the other two grasslands are due to military use. These two factors could explain the abundance in organic content across all sampled Nashigahara plots. With the exception of Plot 1,[2] the majority, if not the entirety of each soil profile, were categorized as having either “abundant” or “moderate” organic material.

The Nojirisōgen proved particularly exhausting to excavate, which resulted in a single plot sample from the grassland. Because we did not reach parent rock or a known lava flow, we can only assume that the bottom-most layer exceeded our 290 cm hole in depth. The volume of scoria indicates that the Nojirisōgen was likely buried by tephra from the Omuro crater during an eruption sometime between 3500 and 2900 years ago (Takada et al, 2007). Compared to the Motosukōgen and Nashigahara, the Nojirisōgen had much less organic material in its deeper soil horizons. This may be because the scoria deposited by the Omuro eruption made it difficult for plants to inhabit the area until more deposits or erosion created more favorable conditions for growth. Since this grassland is considerably smaller than either of the other two grasslands, we hope that the single sample we observed is adequately representative of the grassland as a whole.

Although we expected age to have a positive correlation with soil depth, our data revealed that this was not reliably consistent. The two deepest soil profiles came from the two younger grasslands. If a lava flow is geographically well-positioned to receive deposits from tephra or *yukishiro*, we might anticipate deeper soil profiles. Our current results suggest that tephra and *yukishiro* may be significant contributors to soil depth, but a new study with an emphasis on debris pathways would be necessary to confirm this hypothesis.

While the effects of *yukishiro* deposits on soil composition can be difficult to discern without knowing the pathway, volume, and components of historic, the effects of airborne tephra are more immediately apparent. Small pieces of scoria were present in high volume at a few plots, indicating deposits from volcanic activity. On the Nashigahara and Nojirisōgen, scoria deposits dominated the bottom layer of the soil profile. On the Motosukōgen, deep volcanic clasts on top of a thin organic layer indicate volcanic activity on a somewhat-developed grassland. On the grasslands, tephra deposits were rarely near the surface; we can assume that this is because thick grassy vegetation cannot grow on nutrient-poor, porous gravel. We suspect that more organic or weathered soil deposits closer to the surface are the result of *yukishiro*.

The effects of human land use are also difficult to determine because the grasslands were all maintained for similar durations on a geologic time scale. Changes to land management within the last century will be difficult to observe in soil profiles. Older soil differences reflecting the

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[2] Plot 1 had several horizons of scoria and basalt gravel, which could have been deposited by volcanic activity and therefore prevented rapid plant succession.

beginnings of human occupation and management might be more discernable, but our current research does not confirm that human land management is solely responsible for the observed amounts of organic material. However, given the existence of lush grasslands thriving on humic topsoil, anthropogenic fires and mowing might explain soil content if a future study could show *yukishiro* to be insufficient in introducing the amount of organic material currently present in grassland soil.

Conclusion:

The Motosukōgen, Nashigahara, and Nojirisōgen grasslands all lie on the northern foot of Mt. Fuji, but each has a distinct soil profile and a unique geologic history. Our research indicates that the age of the underlying lava flow does not directly correlate with the depth of the soil. We can also conclude that much of the soil is deposited from external sources such as volcanic activity, human management, and debris flows. The location of a grassland relative to other features, which determines its vulnerability to geomorphic processes, is most important for build-up of soil and plant succession over time.

References:

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