

EFFECTS OF HIGH-INTENSITY FOREST FIRES ON SOIL CLAY MINERALOGY

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Abstract: High-intensity forest fires can degrade, collapse, or completely destroy clay minerals in soils, with signatures of these changes remaining for years after the burns. To ascertain immediate impacts of high-intensity fire on soil clay minerals and mineral recovery over time, soil from the 2002 Hayman, Colorado, fire was analyzed by X-ray diffraction. Sample locations included burned soil from within the perimeter of the fire, unburned soil near the origin, and soil from adjacent historic burns. The unburned soils contain mixtures of illite, mixed-layer illite/smectite and illite/vermiculite, kaolin, and mixed-layer chlorite. Surface soils (surface–7.7 cm) contain illite, mixed-layer illite/smectite, and kaolin. Sub-surface soils (7.7–13.0 cm) contain mixed-layer illite/vermiculite, in addition to the same minerals found at the surface. Deep soils (13.0–27.0 cm) show disappearance of mixed-layer illite/smectite and illite/vermiculite and show evidence of the presence of mixed-layer chlorite. Comparisons between recently and historically burned soils and unburned soils showed slight trends in alterations of clay mineral structures in the surface soil, including alteration of the 001 illite peak, the 001 kaolin peak, and a decrease in the swelling component of mixed-layer illite/smectite. These trends indicate fire impacts the structure of soil clay minerals. [Key words: clay minerals, illite, forest fire, Colorado, pedogenesis.]

INTRODUCTION

Forest fires are categorized on the basis of their intensity. These categories can be described as light, moderate, and severe burns, corresponding to low-, moderate-, and high-intensity fires. The intensity of burning depends on several soil and environmental parameters, especially on the fuel type and duration (Ulery and Graham, 1993; Robichaud et al., 2000). The severe-burn or high-intensity fires, which can produce soil surface temperatures in excess of 500° C (Ulery and Graham, 1993), may produce temperatures of 288° C to depths of 2.5 cm (Boyer and Dell, 1980). Forest fires classified as severe burn, or high intensity, significantly change the color of the top layer of mineral soil, typically to reddish, and the color of the next 1.25 cm, which becomes blackened from organic matter charring by heat conducted through the top layer (Boyer and Dell, 1980).

Forest fires can affect a variety of soil components and processes, such as vegetation recovery rate, microorganisms, organic matter, texture, water repellency, surface erosion, productivity, chemistry, and mineralogy. Ulery et al. (1996) suggested that conditions during fires may be suitable for the decomposition, dehydration, or collapse of many phyllosilicate minerals. The complete decomposition of kaolinite can occur in severely burned soils in the uppermost layers (1–8 cm depths) (Ulery et al., 1996; Iglesias et al., 1997). Dehydroxylation of the 2:1 octahedral sheet and the interlayer hydroxide sheet may lead to decomposition of other minerals such as chlorite and chlorite-vermiculite (Sertsu and Sanchez, 1978; Boyer and Dell, 1980; Ulery et al., 1996). Other phyllosilicate minerals, such as micas and vermiculite, may be impacted by high-intensity fire without being completely decomposed (Ulery et al., 1996). Dehydroxylation can cause a decrease in the 001 d-spacing of mica (Ulery et al., 1996; Castelein et al., 2001). Vermiculite's 001 d-spacing may collapse as a result of forest fire due either to dehydration of interlayer cations or as a result of K released by combustion of organic matter (Nettleton et al., 1973; Ulery et al., 1996; Arocena and Opio, 2003). The 001 d-spacing is from one dimension of the unit cell due to orientation of the clay sample during preparation. It relates to the perpendicular distance between 001 planes. There is indication that these, and other, alterations to the soil following burning will persist over time, for up to tens of years (Ulery et al., 1996; Iglesias et al., 1997; Cannon et al., 2002).

This study evaluates the impact of high-intensity forest fire on the crystalline structure of soil clay minerals with depth in recent and historic burns. Little research exists that evaluates alteration and recovery of soil clay minerals following five to 100+ years after the last burn event. Short-term impacts are evaluated by examination of areas burned in the 2002 Hayman, Colorado fire. Long-term impacts and recovery status are examined based on areas that experienced fire up to 100+ years ago located in the vicinity of the Hayman fire.

MATERIALS AND METHODS

Area Description

The study area is located in the Pike National Forest in central Colorado, United States, in the area of the 2002 Hayman, Colorado forest fire (Fig. 1), which burned ~56,000 ha. Regional climatic conditions from several years prior produced an ideal environment for the fire to burn on June 8, 2002. According to Graham (2003), drought conditions, coupled with a three-year-long La Niña event, produced the driest fuel moisture conditions of the past 30 years.

The area, in the Front Range of the Rocky Mountains, consists of Precambrian plutonic crystalline rock overlain by Paleozoic and Mesozoic sedimentary rock (Bradley, 1987). The current topography of the area is the result of early and mid-Cenozoic structural uplift and erosion, followed by Pleistocene glaciations and melt-water (Bradley, 1987; Birkeland et al., 2003). The soil types of the study area include the Sphinx (Typic Ustorthents), Legault (Typic Cryorthents), Boyett-Frenchcreek (Mollic Eutroboralfs–Aridic Haploborolls), and Pendant (Lithic Haploborolls) and range from clay loams to loamy sands that are all well to somewhat excessively

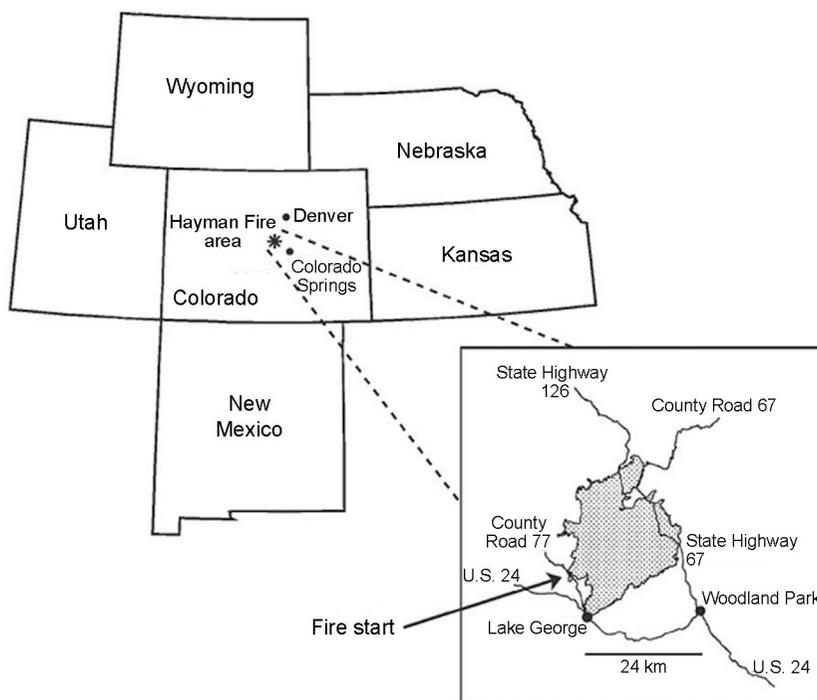


Fig. 1. Location of the 2002 Hayman, Colorado fire (from Graham, 2003). The Hayman Fire, which burned ~ 56,000 ha, is located within Pike National Forest in central Colorado.

drained (Moore, 1992). Parent material is primarily Pikes Peak granite, with some soils formed from weathered limestone or alluvium derived from mixed arkosic sandstone and granite (Moore, 1992). These soils support the growth of *Pinus ponderosa*, *Pseudotsuga menziesii*, *Festuca spp.*, as well as several other montane and subalpine varieties (Moore, 1992). Typical soil properties can be seen in Table 1.

Soil Sampling

Soils were sampled one to four months after the 2002 Hayman fire from 13 sites in and around the burn perimeter (Fig. 2A) (Table 2). These sites were selected based on burn intensity as well as the date of the most recent burn (Figs. 2A–2B). Areas of high burn intensity were chosen and were determined based on field observations, such as high fuel loads shown by greater than 20 cm of completely combusted pine needles, sterile soil, complete tree mortality, hydrophobicity, oxidation of A horizons, and physically weathered rocks due to extreme surface heat. Sampling sites were located on ridge tops or level valley bottoms of granitic parent material to minimize the effect of slope and lithology on soil formation. Vegetation of the areas varied slightly, although all were part of the montane and subalpine forest ecosystem. The majority of samples (HAO-1, HKG-1–3, MLG-1–2, SXC-1, WCK-1, and WIG-1) were collected from the area within the Hayman Fire perimeter (Figs.

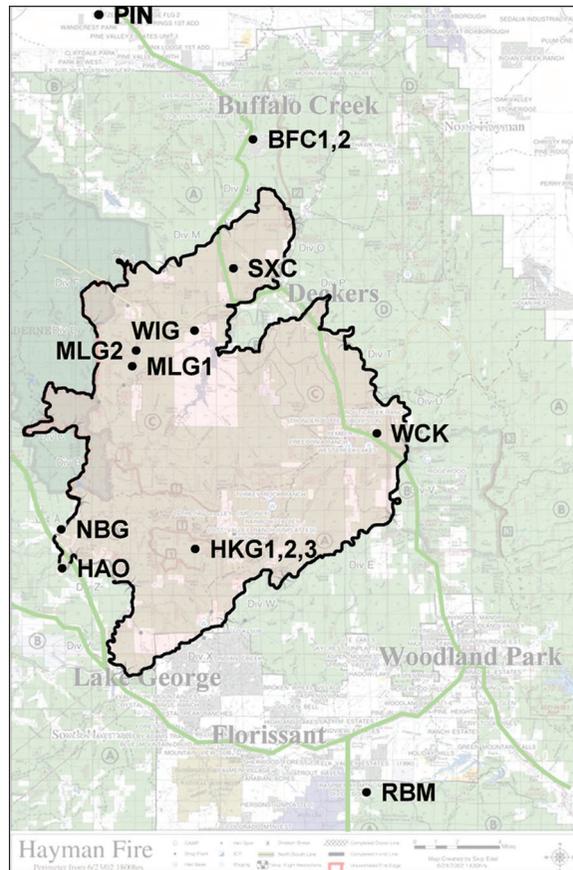


Fig. 2. A. Sampling locations in and around the Hayman, CO fire perimeter (base map used with permission from USFS, 2002). Site NBG is the control; Sites BFC-1, BFC-2, PIN, and RBM represent historic burns outside the Hayman perimeter; all other sample sites represent Hayman-burned soils. All samples were from areas of similar lithology, ecology, and geomorphic surface. All Hayman burned samples were from areas of high fire severity. B. (facing page) Burn severity of the Hayman, CO fire based on remote sensing imagery (used with permission from Mark Finney, United States Forest Service). Burned samples were collected from within high-fire-severity locations.

3A–3B), whereas others were collected from areas outside the perimeter. These samples include NBG 1 (Fig. 3C), located near the origin of the fire, just outside the perimeter, PIN-1 (last burn 2000), BFC-1 (last burn 1996), and RBM-1 (last burn prior to 1898)—all located outside the burn area. The gaps in the chronology of burn dates are due to either the absence of fire as a result of fire suppression management or to the uncertainty of documented fire.

Soils were collected by full pits (1 m × 1 m × 1 m), short pits (< 1 m × 1 m × 1 m), and coring, depending on the level of sensitivity to land disturbance of the sample locations. Samples were collected at depths ranging from the surface to 68 cm of the post-fire surface. Samples were grouped according to the similarity of the depth to which they were taken: surface soil (surface to 7.7 cm); subsurface soil (7.8 to 13

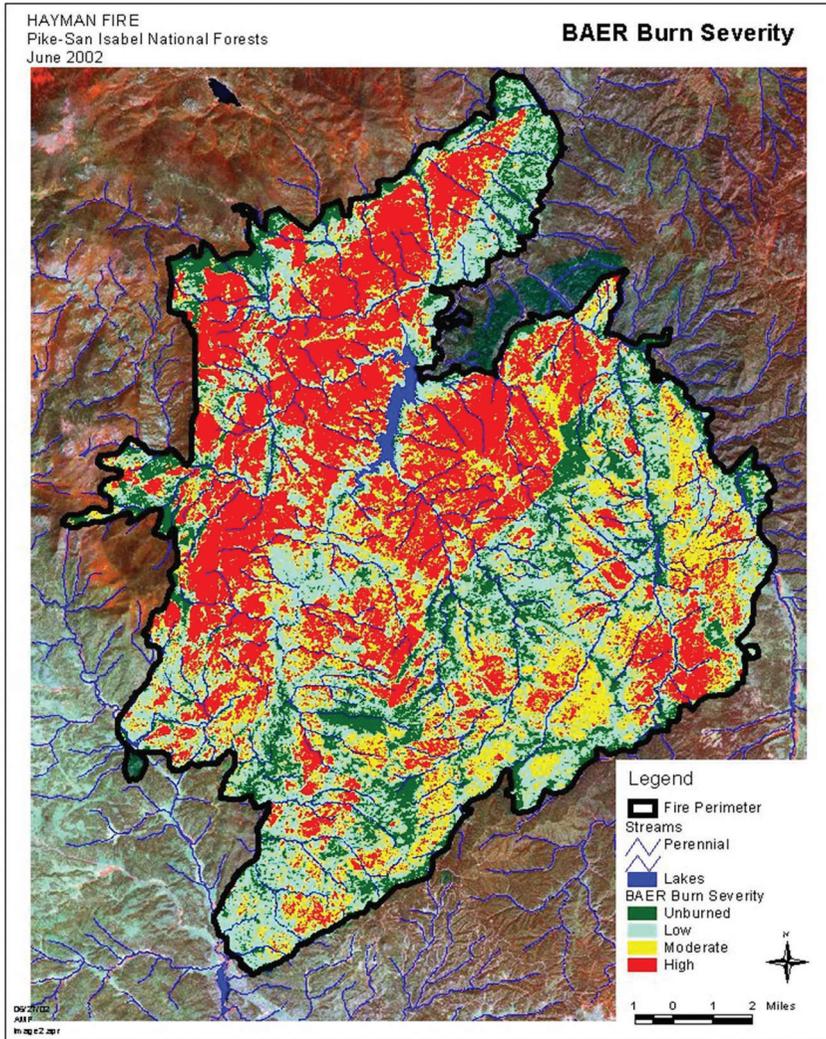


Fig. 2. B. *continued.*

cm); deep soil (13.1 to 27+ cm). Consistency of depths was difficult to maintain due to the mix of sampling techniques. Soil groups were chosen based on the depths to which heat is transferred in the soil as a result of fire. In general, the greatest temperatures are reached at the surface to depths of about 5 cm (Neary et al., 2005). Surface samples were chosen below 5 cm in anticipation of deeper heat transfer from the high-intensity fire.

Mineral Identification and Structural Analysis

Prior to clay separation from the bulk soil, organic material was removed using the sodium hypochlorite (NaOCl) method as described by Moore and Reynolds (1997).

Table 1. Representative Soil Properties of the Hayman, CO Sample Sites

Sample	Horizon	Depth (cm)	Wet hue value/ chroma	Dry hue value/ chroma	Structure ^a
MLG-2	AO	<1.0	10 YR 2/1	10 YR 3/1	sg vf gr
	A	1.0	10 YR 2/1	10 YR 3/1	1–2 vf-f sbk
	B1	14.5	10 YR 3/2	10 YR 4/3	2 vf sbk
	B2	32.5	10 YR 3/4	10 YR 5/3	1 vf sbk
	B3	48.0	10 YR 3/2	10 YR 4/3	2 c pl
HAO-1	Ash	<1.0	2.5 YR 2/0.5	2.5 YR 3/1	2 c pl
	AO	0.5	7.5 YR 4/6	7.5 YR 7/6	sg
	A1	2.5	10 YR 2/1	10 YR 4/2	2 m abk
	B1	6.5	10 YR 4/4	10 YR 4/6	1 vf-f abk
	B2	21.5	7.5 YR 4/4	10 YR 4/6	2 m abk
	B3	32.5	5 YR 4/4	5 YR 5/6	3 vf abk
WCK-1	AO	<1.0	5 YR 2/0.5	5 YR 2/0.5	1 vc pl
	A1	2.0	10 YR 2/2	10 YR 4/3	n.a. n.a. abk
	A2	7.0	7.5 YR 3/3	7.5 YR 5/3	3 n.a. abk
	B1	27.0	7.5 YR 3/4	7.5 YR 4/4	n.a. n.a. abk

^aGrade: 1 = weak; 2 = moderate; 3 = strong; sg = single-grain; m = massive. Size: vf = very fine; f = fine; m = medium; c = coarse; vc = very coarse. Type: abk = angular blocky; gr = granular; sbk = subangular blocky; pl = platy (Birkeland, 1999).

Table 2. Field Properties of the Sample Sites

Site	ID	Elevation (m)	Fire intensity	Burn date	Vegetation
Tarryall Road	NBG-1	2573	Control	>1850	Douglas fir, ponderosa pine
Raspberry Mtn	RBM-1	2914	High	>1898	Aspen, limber pine
Buffalo Creek	BFC-1	2316	High	1996	Ponderosa pine
Pine	PIN-1	2271	Moderate	2000	Ponderosa pine, Douglas fir
Hackett Gulch 1	HKG-1	2803	High	2002	Ponderosa pine, Douglas fir
Hackett Gulch 2	HKG-1	2804	High	2002	Ponderosa pine, Douglas fir
Hackett Gulch 3	HKG-1	2797	High	2002	Ponderosa pine, Douglas fir
Hayman Origin	HAO-1	2618	High	2002	Ponderosa pine; aspen
Molly Gulch 1	MLG-1	2407	Extreme	2002	Douglas fir, ponderosa pine
Molly Gulch 2	MLG-1	2385	Extreme	2002	Douglas fir, ponderosa pine
Six Mile Creek	SXC-1	2190	High	2002	Ponderosa and lodgepole pine
Westcreek	WCK-1	2416	High	2002	Douglas fir, ponderosa pine
Wigwam Road	WUG-1	2277	High	2002	Ponderosa pine



Fig. 3. A. Soil profile of HAO-1 collected at the origin of the Hayman Fire. Note the oxidized A horizon. B. Soil profile of MLG-1 collected inside the perimeter of the Hayman Fire. Note the ashy A horizon and relatively unaffected B horizon. C. Soil profile of NCG-1 collected outside the perimeter of the Hayman Fire. Sample NCG-1 represents the control soil that has not burned in 150 years.

The clay minerals ($< 2 \mu\text{m}$) were separated from the soil and prepared for analysis by a Phillips X'PERT PRO X-ray diffractometer using the smear mount method per Moore and Reynolds (1997). X-ray diffraction (XRD) parameters were set at 45 kv,

40 mA, a continuous scan with a step size of 0.02 and time per step of 2 sec, and CuK α radiation. Identification of individual clay minerals was performed by comparative XRD analysis of air-dried, glycollated, and furnace heated to 400° C and 550° C samples of the 3–50°2 θ range as described by Moore and Reynolds (1997) and Poppe et al. (2001). All glycollated and heat-treated samples were analyzed immediately upon removal from the treatment chamber. The XRD traces produced by these treatments were then analyzed for differences that may have occurred due to the high-intensity fires to which the soils were exposed. All spectra were compared to those of sample NBG, representing the control soil.

Statistical Analysis

Analysis of Variance (ANOVA) was used to test for significance of differences ($p < 0.05$) within each soil depth (surface, subsurface, deep). Each sample had a series of variables including specific XRD d-spacing, burn category (1 = control; 2 = historically burned; 3 = recent burn), current vs. noncurrent burn (1 = noncurrent: most recent fire >2 years ago; 2 = current: most recent fire <2 years ago), depth level, and site code (1–16 sample sites). The XRD d-spacing variable was used as the dependent variable for ANOVA with all other variables as independent. Correlation and linear regression were used if two variables were found to be significantly correlated within a given depth.

RESULTS AND DISCUSSION

Control Soil

The control soil (NBG) has had no documented burns since at least the 1850s. However, while there are no scientific data to prove this, there is a historical account that states this area of Colorado was burned in the mid-1850s, before European settlement of the area (Sommers, 1965). It is believed that a fire set by the Arapahoe or the Cheyenne burned in 1853 or 1854 for three straight weeks under constant high wind and burned approximately 113 km of terrain (Sommers, 1965) in which the study area is located. Figure 4 represents the XRD trace for the control soil at each depth and indicates the presence of illite (I), mixed layer illite/smectite (I/S), illite/vermiculite (I/V), kaolin (K), mixed-layer chlorite (C), as well as some clay-sized quartz (Qtz), plagioclase (Plag), and potassium feldspar (K-spar).

Surface Soil

Comparisons of the clay mineralogy of NBG-1A with samples burned in the 2002 Hayman Fire showed some marked differences. Samples compared with control surface soils from areas of high fire intensity show a decrease in the 001 peak of glycollated illite/smectite (HAO-1A). Many samples showed shifts in the 001 peak of illite and kaolin and the glycollated 001/002 peak of illite/smectite (Figs. 5–6) as well as differences in ordering of illite/smectite from random interstratification of the control soil to evidence of Reichweite $R = 1$ (R1) ordering (HAO-1A, MAT-2A, MLG-1A,

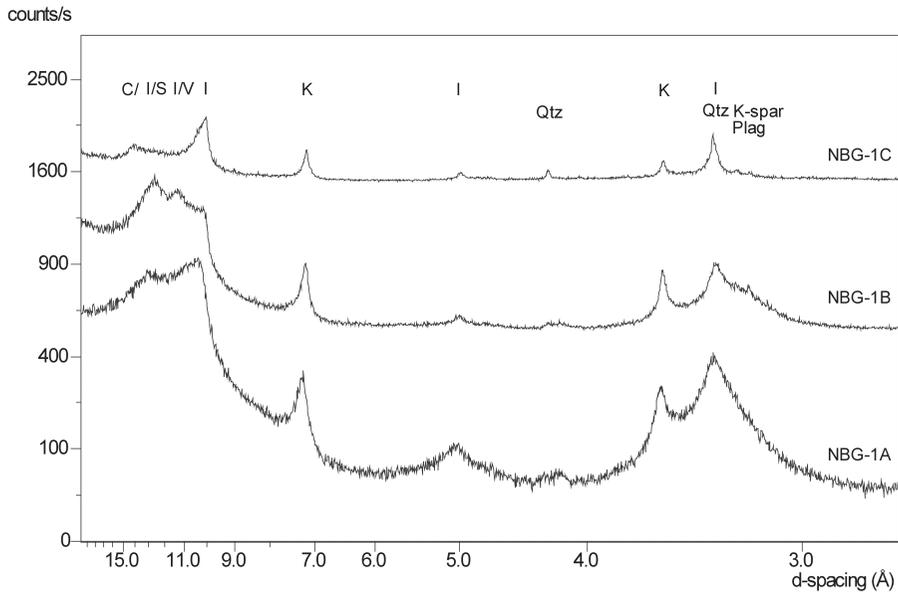


Fig. 4. X-ray diffraction tracings of untreated control soils NBG-1A containing illite (I), mixed-layer illite/smectite (I/S), and kaolin (K); NBG-1B, with addition of mixed-layer illite/vermiculite (I/V), and clay-sized quartz and plagioclase; NBG-1C (with loss of I/S, I/V and addition of mixed-layer chlorite (C) and clay-sized potassium feldspar (K-spar)).

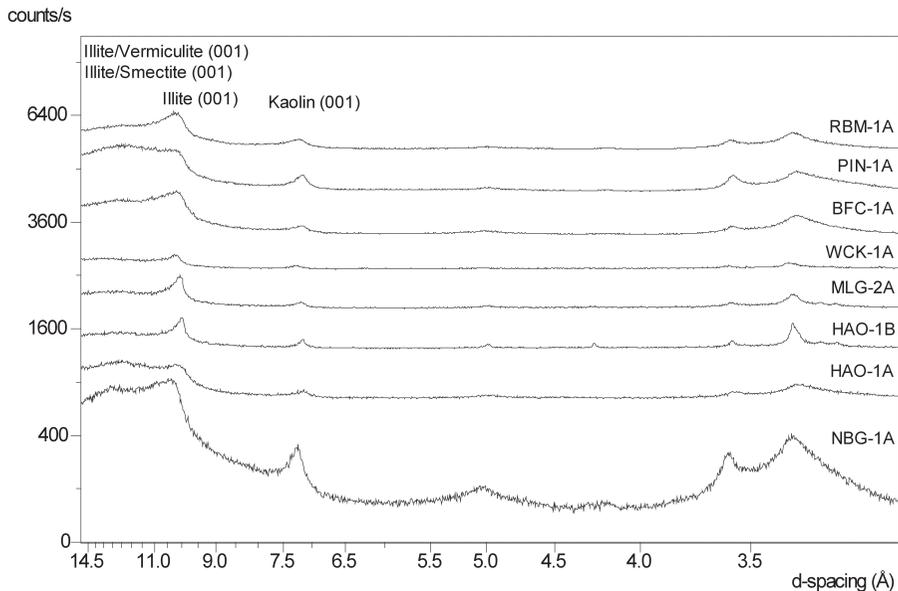


Fig. 5. Representative XRD tracings of untreated surface control soil (NBS-1A), Hayman burned soils (HAO-1A, HAO-1B, MLG-2A, WCK-1A), and historically burned soils (BFC-1A, PIN-1A, RBM-1A), illustrating 001 peak positions of illite, illite/smectite, illite/vermiculite, and kaolin.

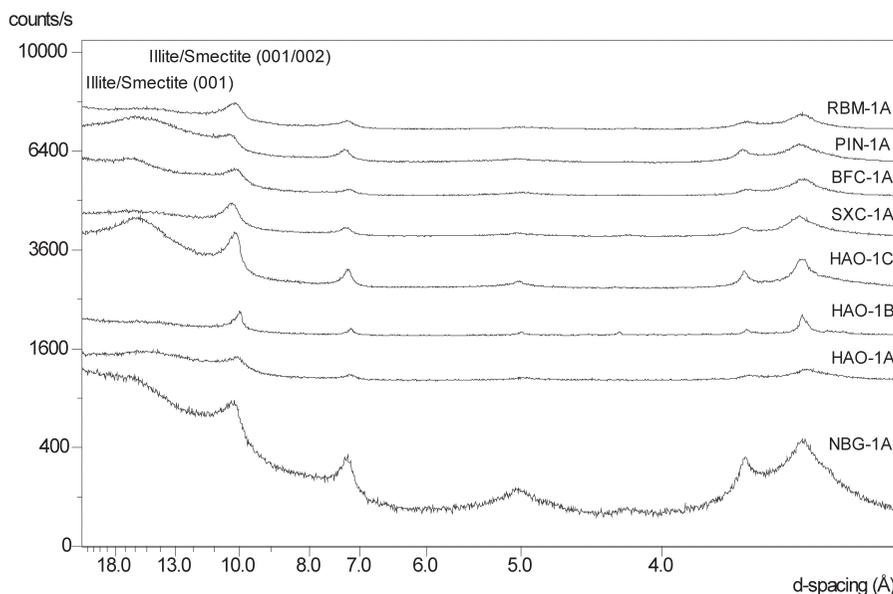


Fig. 6. Representative XRD tracings of ethylene glycol-treated surface control soil (NBG-1A), Hayman burned soils (HAO-1A, HAO-1B, HAO-1C, SXC-1A), and historically burned soils (BFC-1A, PIN-1A, RBM-1A), illustrating 001 and 001/002 peak positions of illite/smectite.

WIG-1A). Reichweite is related to the stacking order of the layers, in this case, the illite and the smectite layers, where illite is always separated by a smectite layer. WCK-1A differs from the control in that it contains illite/vermiculite rather than illite/smectite. One sample (MLG-1A), which experienced extreme fire intensity, contains the same clay mineral assemblage as the control but also contains an 8.5 Å peak, which remains through all experimental treatments. The mineral associated with this peak cannot be determined with the given data, which may be due to the masking of other relevant peaks by the already-established clay mineral peaks. It is likely this mineral is a clay-sized primary mineral, possibly an amphibole.

NBG-1A was also compared to the historically burned surface soils and showed only slight differences in clay mineral peaks. These differences were in slight decreases in d-spacing measurements of the 001 peaks of illite and kaolin in all samples (Figs. 5 and 6). RBM-1A, however, does show a marked decrease in the glycollated 001 peak of illite/smectite and shows evidence of R1 ordering.

Statistical analysis of the surface soils, however, indicates significant differences only for a few of the clay mineral d-spacing changes observed. The 001 illite peak was found to be significantly different in terms of burn category ($p = 0.037$) and relative age of the burn ($p = 0.024$). The glycollated 001/002 illite/smectite peak was also found to be significantly different in terms of relative age of the burn ($p = 0.020$). There was also a correlation of the 001 illite to the 001/002 illite/smectite peaks ($R^2 = 0.516$) in terms of current burns.

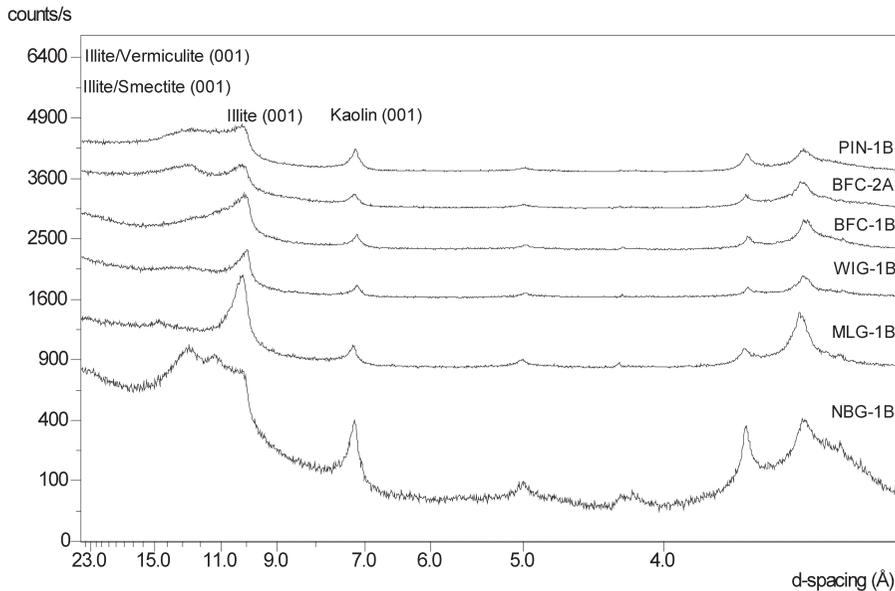


Fig. 7. Representative XRD tracings of untreated subsurface control soil (NBG-1B), Hayman burned soils (MLG-1B, WIG-1B), and historically burned soils (BFC-1B, BFC-2A, PIN-1B), illustrating 001 peak positions of illite, illite/smectite, illite/vermiculite, and kaolin.

Subsurface and Deep Soils

Comparisons of the control soils NBG-1B and NBG-1C with both Hayman burned and historically burned samples showed much greater variation among samples than those compared in surface soils (Figs. 7–8). The variability in mineralogy and mineral d-spacings among subsurface and deep soils did not show any statistical significance. This was the expected result. Temperature tends to decrease rapidly as it penetrates deeper into the soil; therefore, the heat of the fire typically only impacts the upper few centimeters of the soil layer (Fig. 3B). The assumption can therefore be made that due to the depth from the surface of these samples, changes did not occur as a result of fire and are most likely due to normal weathering and soil formation.

The control sample NBG-1A contained illite, mixed-layer illite/smectite, and kaolin. In comparison, the only burned sample in the surface soils with a change in mineralogy was WCK-1A, which lacks illite/smectite but has illite/vermiculite (Fig. 5). One possibility for this difference may be in the age and normal weathering sequences in soils. Egli et al. (2003) discusses the transformation of illite \rightarrow vermiculite \rightarrow illite/smectite \rightarrow smectite in regards to soil formation over time and suggests this sequence is pronounced in the early stages of soil formation. A second possibility may be that the appearance of the illite/vermiculite occurred from weathering of illite as a result of the fire, with fire acting as a catalyst for the weathering process. However, more research with a larger sample size is needed for a conclusive determination.

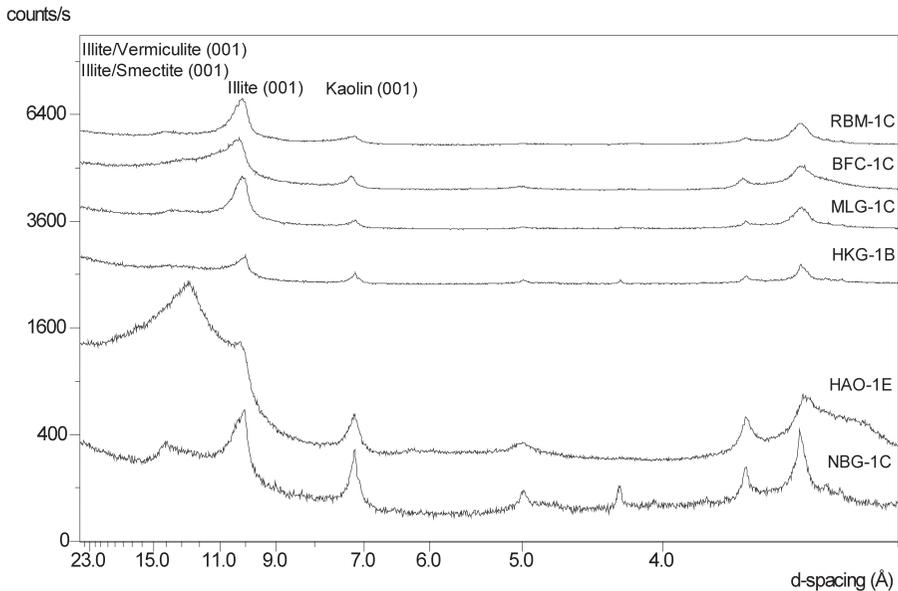


Fig. 8. Representative XRD tracings of untreated deep control soil (NBG-1C), Hayman burned soils (HAO-1E, HKG-1B, MLG-1C), and historically burned soils (BFC-1C, RBM-1C), illustrating 001 peak positions of illite, illite/smectite, illite/vermiculite, and kaolin.

Many of the samples experienced some change in d spacing. For example, all burned samples contained kaolin peaks, which, upon heating to 550° C were destroyed, indicating the fire in the study area was not hot enough to destroy all kaolin. Slight shifts in peak positions were observed in the majority of the 15 soil samples. This signature is also evident in historically burned soils 2 to 100+ years post burn. It is unclear at this time if the shifts in the peak position are related to natural variation or a result of fire intensity. This result in kaolin, however, is not what was expected. Past studies have indicated the destruction of kaolin with intense fire, which was the expected result. The indication in this study that kaolin is not being destroyed is consistent with the findings by Arocena and Opio (2003) in their study of lower-intensity prescribed burns. In this case, the temperature of the soil did not reach the temperature needed (500° C) to destroy kaolin. It is possible that the Hayman Fire was not hot enough or did not burn long enough to allow enough heat to penetrate the soil to cause the complete destruction of the kaolin structure. Another possibility for the lack of destroyed kaolin may be due to the dry conditions of the area, which may not have allowed for heat conduction needed to raise the soil temperatures to 550° C or greater.

In addition to slight shifts in the kaolin peak positions, changes in d spacing can also be seen in the 001 illite peak from 10.2Å to 10.1Å or less, which occurred in the majority of samples including historically burned ones. These alterations do show significant differences between Hayman burned, historically burned, and unburned soil samples by ANOVA testing ($p = 0.037$). The shifts in the peak positions of the

burned soils may be due to dehydroxylation as suggested by Sertso and Sanchez (1978), Boyer and Dell (1980), and Ulery et al. (1996), as all forms of clay lose water derived from hydroxyl ions at high temperatures, which would result from high fire intensity. The difference was also statistically significant ($p = 0.024$) when comparing Hayman vs. non-Hayman sites, possibly an immediate post-fire product that declines over years. We suggest that increased fire intensity or exposure, leading to increased weathering of illite, may result in a substantial decrease in potassium available to be released in a long-term period. Illites and larger-sized micas are primarily responsible for the release of potassium needed for plant nutrition (Dixon, 1991). This potassium becomes increasingly less available in older, more weathered soils where illite and mica contents are lower (Dixon, 1991). This study shows that alteration to illite is occurring due to fire. Increased exposure to fire over time, be it higher temperatures, longer duration, or more frequent burning, may result in a reduction of available potassium. Further research is needed, however, in this area.

Mixed-layer illite/smectite peaks show changes in the amount of swelling of the smectite component, as indicated by the 001 peak position in the glycolated state (Fig. 6). The glycol-treated 001 peak expanded to 16.2\AA in the unburned soil, whereas soils burned in the Hayman fire expanded only to $14.2\text{--}16.0\text{\AA}$, with the exception of SXC-1A, which experienced greater expansion. Historically burned soils show variation in the expansion from considerably less than to greater than the control (Fig. 6). However, while these changes may indicate a trend of decreasing expansion with fire exposure, there is no statistical significance to support it. There may be long-term implications associated with this trend. Smectite, as well as vermiculite, is an important mineral in terms of cation exchange capacity. Collapse of smectites may decrease the mineral's cation exchange capacity, therefore allowing essential nutrients for plants to be leached out of the soil horizon. Similar to d-spacing decreases to illite's structure, smectite collapse may not appear problematic currently, but increasing the frequency of soil exposure to fire may result in detrimental effects to the ecosystem in the long term.

The expected results for the surface soils studied were statistically significant shifts in clay mineral d-spacing based on exposure to fire vs. control soil. Comparisons of the control to the historically burned soils were expected to show evidence of attainment of pre-fire conditions with time. The results of this study, however, did not indicate this. While this is the case, the data still suggest change due to fire. The changes that resulted from the Hayman Fire may not be statistically significant as expected, but are still occurring. A possible explanation for these results is that the heat generated from the Hayman Fire did not penetrate the soil with the same intensity as is observed in the above-ground, fire-related impacts of the area (Fig. 2B). A second explanation may be that the heat did penetrate the soil sufficiently deeply, but the duration of the soil heating may not have been long enough to cause the expected changes to the clay minerals. The amount of heat to which these soils were exposed appears to have been sufficient (and sufficiently long) to begin alteration of the minerals, but not enough (either in temperature and/or duration) to cause complete alteration of mineral structures. A third possibility may relate to differences in tree densities, as suggested by Goforth et al. (2005), which were not a factor measured in

this study. A more in-depth study of fire behavior and tree densities in the sampling areas could be undertaken in order to assess these possibilities.

Two additional factors may have influenced the results for the surface soils in this study. First, there is historical evidence that the area may have burned intensely in the 1850s. This may have substantially affected the soil and left signatures that may still be evident. While there are no scientific data available for the 1850s burn, it may help to explain the results of this study. Second, expected long-term effects may not be evident in this study because soils sampled from the historic fires were not exposed to fire following the date of the reported burn event. They show how clay mineral alteration may change or persist over time from high-intensity fire, but not what happens as a result of more frequent fire exposure.

The comparison of samples with NBG-1B and NBG-1C, which represent sub-surface and deep soils (below 7.8 cm depth), have too many natural variations due to normal soil-forming processes to make assumptions based on fire intensity. The results showed a wide range of differences among samples; none, however, were statistically significant, which had been the expected result. The results for this study indicate slight peak shifts among the minerals in the top portion of the soil. This observation also provides support that the changes in the deeper portion of the soil are not a result of fire intensity. Soil temperature induced by fire will rapidly decrease with depth; therefore, if the heat was not intense enough in the upper 7.7 cm of the soil to cause significant changes, it would follow that the deeper regions of the soil should not be affected by the fire at all.

CONCLUSIONS

The conclusions to be drawn from this study are based on the results of the comparisons of the control soil NBG-1A with Hayman and historically burned surface soils. The results, some lacking statistical support, indicate that fire is impacting the structure of the clay minerals with some modifications remaining evident over time. We expected, however, to observe more significant modifications, as samples were chosen from areas exhibiting evidence of high fire intensity. Intensity ratings of wild-fire do not appear to have a direct correlation to the intensity of soil heating. The alterations to the soil clays observed here, which varied with clay type, suggest that long-term, frequent fire impacts need to be evaluated. A more accurate assessment of the fire intensity and resulting heating of the soil in the sampling sites may provide needed information to determine whether or not the fire intensity at the soil surface was as high as indicated from the overall area. Lower fire temperatures could be a major explanation of why the alterations of the clay minerals were so slight. Assessment of the implications of more frequent burns on soils should also be done to determine the effects of fire in the long-term, as recovery will differ in an area of a single burn as opposed to several burns. Evaluation of clay mineral modifications resulting from fire should continue, as clays are the most active mineral constituents in soils (Dixon, 1991), continually influencing physical and chemical soil properties. Alteration of clay minerals in soils may lead to modifications of other soil properties.

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