

Fire and the Prairie-forest Mosaic of Devils Tower National Monument

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ABSTRACT: The pattern of vegetation types has changed markedly at Devils Tower in the past 100 years. Fire scars on ponderosa pine (*Pinus ponderosa* Laws.) at the Monument indicate that there has been a marked change in fire frequency over this period. Changes in fire regime are clearly important in driving the changes in vegetation pattern. Studies of soil-borne opal phytoliths also indicate the presence of a stable ecotone in the past followed by a dynamic boundary in recent times. Changes in fire frequency from 1770-1900, a time when the Sioux were rapidly expanding into the Black Hills, indicates that native Americans may have dramatically affected the prairie-forest mosaic observed by early Europeans.

INTRODUCTION

Comparison of today's landscape at Devils Tower National Monument with the landscape shown in late 19th-century photographs indicates that a major change has occurred in the area's vegetation over the past 100 years. The area of pine forest (*ponderosa* Laws.) has dramatically increased with a concomitant decrease in the savanna and prairie. Such invasions of forest into grasslands in the arid West are associated with decreases in frequency of wildfires (Kucera, 1981). Such invasions also be due to climatic change or to changing grazing patterns (Saur, 1950; Saur, 1953; Tande, 1979; McNeil and Zobel, 1980).

Frequent, low-intensity, surface fires characterized presettlement ponderosa forests (Weaver, 1951; Cooper, 1960). Since the early part of this century, fire suppression efforts have altered fire frequency and intensity, and vegetation patterns in the West have changed. In the absence of fire, forests commonly increase along forest ecotones (Kucera, 1981). Reduced fire frequency may, however, lead to intense fires when they do occur (Kilgore and Taylor, 1979). This can have severe impacts on the vegetation. This would either drastically reduce the area or cause even-aged forests to replace the all-aged forests that were perpetuated by frequent light fires (Arno, 1980).

In this paper we show that an increase in fire frequency between 1770 and 1900, followed by a dramatic decrease in fire frequency since 1900, is closely associated with the changing prairie-forest mosaic at Devils Tower. We have also used an analysis of soil-borne opal phytoliths to infer that the prairie-forest mosaic was dynamic but stable for a considerable period prior to the late 1700s.

METHODS

Fire history and changes in the prairie-forest mosaic at Devils Tower were investigated using three techniques: (1) Changes in forested area and in forest distribution studied using 1938 and 1978 aerial photography (Gruell, 1983); (2) since the reported old trees (>375 years), dendrochronologic techniques were used to establish past vegetation along prairie-forest ecotones (Witty and Knox, 1960; and Dreas, 1968; Miles and Singleton, 1975).

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pes has changed markedly at Devils Tower. Ponderosa pine (*Pinus ponderosa* Laws.) at the site has experienced a marked change in fire frequency over the past 100 years. The area of pine forest has decreased with a concomitant decrease in the area of grasslands in the arid West. Wildfires (Kucera, 1981). Such invasions, changing grazing patterns (Saur, 1950; Saur, 1960).

INTRODUCTION

Devils Tower National Monument was established in 1906. Aerial photography indicates that a major change in land use has occurred in the past 100 years. The area of pine forest has decreased with a concomitant decrease in the area of grasslands in the arid West. Wildfires (Kucera, 1981). Such invasions, changing grazing patterns (Saur, 1950; Saur, 1960).

characterized presettlement ponderosa pine forests. In the early part of this century, fire frequency, intensity, and vegetation patterns in the area were different. Forests commonly increase along with fire frequency may, however, lead to a decrease in fire frequency (Taylor, 1979). This can have several effects, either drastically reduce the area of forest or maintain the forest mosaic.

METHODS

The forest mosaic at Devils Tower was studied in a forested area and in forest open areas. (1) since the aerial photography (Gruell, 1983); (2) since the same techniques were used to study the forest mosaic. Studies of soil-borne plant opal were conducted in the forested areas and ecotones (Witty and Knox, 1975).

Black and white aerial photography taken in 1938 and 1978 was interpreted to determine certain areas where changes had or had not occurred in the type and density of vegetation. On this basis, 10 transects ranging in length from 250-2500 m and averaging 1500 m were chosen for collection of fire scar data. Transects 1, 3 and 9 represented areas of savanna and forest that had recently become more densely forested. Transects 2, 4 and 5 were across prairie-forest ecotones. Transects 6, 8 and 10 were in forested areas, and transect 7 was in an area of prairie where a few old ponderosa pine occurred in a ravine crossed by the transect. Along these transects the vegetation type was mapped. Any fire scarred tree within 20 m either side of the transect was sampled by extracting a wedge as described by Arno and Sneek (1977). These wedges were dried and sanded, and the rings were counted using a variable-power binocular microscope. The age of the tree and the years in which fire scars occurred were recorded. Each section was counted twice with other sections being counted between these repetitions. Any difference in the two determinations was reconciled by a third examination.

Missing rings, false rings or obscured rings may make ring counts from individual trees inaccurate. We combined the data first from all trees on a transect and then from all trees on the site into a master fire chronology using a modification of the method suggested by Arno and Sneek (1977).

First, the 91 individual tree chronologies were plotted by computer with the cambium-ring year (year section was cut) justified to the left. Years with fire scars in each chronology were marked with an "X" if the cross section was clear and easy to interpret, with a "Y" if the section was difficult to interpret, and with a "Z" if dates had to be approximated due to rot or obscured rings. Then years with fire scars and the total number of type X, Y and Z scars in each year were tabulated. Fifty-two percent of our cross sections were Y-type, 39% were X-type and 9% were Z-type.

The plotted chronologies were then examined for apparent shifts of chronologies. Often all or a portion of the record for a certain tree is consistently out of sequence with the majority of other fire-scarred trees. Such a record can often be brought into sequence by adding a few years at one or more points in time thus moving its fire-scar dates back. Such corrections seem appropriate in light of the fact that Craighead (1927) found that ponderosa pine often ceased to form annual rings for as long as 5 years following severe fire injury.

The following rules were used to adjust individual chronologies and form the master chronology. Fire-scar dates from clear cross sections (X-type) were given more weight than Y or Z-type cross sections. When two or more trees in a geographic area had coincident fire dates, other trees in that area were adjusted so their chronologies matched the fire years. No more than one adjustment was made in any chronology. In total, 10 Z-type and six Y-type cross sections were adjusted.

Opal-phytolith analysis was used in conjunction with the fire-scar analysis. Phytoliths are deposits of noncrystalline silicon dioxide (opal) made in living plant cells. All plants take up silica from the soil in solution along with nutrients and other ions. Some plants (e.g., horsetails and grasses) take up more silica than others (e.g., trees). Each species deposits this silica in cells of different shapes and types thus forming distinctive phytoliths (Geis, 1973; Klein and Geis, 1978). When the plant parts decay, the resistant phytoliths remain behind in the soil. Since silicon dioxide is only very slowly weathered in soils, these phytoliths persist for hundreds, even thousands, of years. Because they are small particles (.05-.01 mm), they do not move through the soil; rather, they accumulate in the upper few centimeters.

The methods used in the phytolith analysis followed those of Kalisz and Stone (1975) and Miles and Singleton (1975) and Rovner (1971). Samples were taken within each transect type along transects 1, 2, 4 and 5. Soil samples were taken by removing the surface litter and taking about 200 g of soil from the 0-15 cm depth. Plant material consisting of needles and leaves was collected for phytolith analysis from ponderosa pine, mountain juniper (*Juniperus scopulorum* Sarg.), bur oak (*Quercus macrocarpa*

Michx.), needlegrass (*Stipa* sp. L.), wheatgrass (*Agropyron* sp. Gaertn.) and bromegrass (*Bromus* sp. L.).

In the laboratory, duplicate samples of 5-10 g of soil were analyzed for the percentage of opal phytoliths by weight. The procedure used followed Rovner (1971), except that a solution of 30% hydrogen peroxide (H_2O_2) was used to remove organic matter instead of a dilute solution of HCl. The final amounts of phytolith were inspected under a compound microscope to assure uniform purity and were then weighed and averaged to determine the soil's phytolith content. Differences in phytolith content were tested using a t-test for unpaired observations with unequal variance.

Plant material was analyzed following Kalisz and Stone (1984). Samples of opal phytoliths of each species were put on slides and compared with phytoliths extracted from soil samples.

RESULTS

The majority of trees sampled showed evidence of fire occurring in the same 15 years since 1600 (Table 1). Trees bearing fire scars in these years occur in every portion of the Monument, indicating that in those years fires burned over the entire area with sufficient intensity to produce fire scars. The fires in these years have been classed as area-wide or regional fires.

There were 14 fires that produced many scars but only on trees in a portion of the Monument (Table 2). When a fire was represented by scars on trees that occurred scattered over at least one third of the area, it was classified as a local fire. The pattern of occurrence of fire-scarred trees indicated that nine of these fires started near the Tower and five burned the entire eastern portion of the area. Five fires burned the western portion of the area including the Tower area and one fire burned the west side of the Monument but stopped short of the Tower.

The trees sampled indicated 53 spot fires that scarred only one tree or a small group of trees. For example, of the 40 fires evidenced by scars along transect 3, 17 occurred on only one tree and scars in that year did not occur on adjacent transects.

The frequency of area-wide fires at Devils Tower has changed dramatically since

TABLE 1. — Dates of area-wide or regional fires as inferred from the occurrence of fire scars throughout the area in any one year

1632	1730	1791	1869
1660	1769	1806	1893
1676	1776	1820	1937
1694	1785	1845	

TABLE 2. — Dates of local fires as inferred from the occurrence of fire scars scattered over a portion of the area

1620	Tower area	1859	Tower area
1695	West side		and east side
1714	Tower area	1864	Tower area
1753	Tower area	1875	Tower area
	and west side		and east side
1760	Tower area	1886	Tower area
	and west side		and east side
1765	Tower area	1890	Tower area
1836	Tower area		and west side
	and northeast	1921	Tower area
1838	Tower area		and east side
	and west side		

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TABLE 3. —

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1791	1869
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1859	Tower area and east side
1864	Tower area
1875	Tower area and east side
1886	Tower area and east side
1890	Tower area and west side
1921	Tower area and east side

00. Prior to 1770 the mean period between fires was 27 years. From 1770 to 1900 the
time between area-wide fires was only 14 years. Since 1900 the fire return period
lengthened to 42 years. If we use 1900 as the date after which most permanent set-
tlement occurred in the area, then the presettlement fire return period was 19 years.
is less than half the time between fires since settlement.

Opal was extracted from 25 plots: 11 in prairie, five in savanna, and nine in forest
(Table 3). The average content of phytoliths in savanna areas was significantly
greater than in forest areas, and the content in prairie areas was significantly greater
than in savanna areas (Table 4). The percentages of plant opal in the soil from these
three vegetation types are similar to those found by Miles and Singleton (1975) in the
Wind River Mountains of Wyoming.

Phytoliths extracted from the soil of prairie plots were overwhelmingly grass phyto-
liths. The majority were of wheatgrass or brome grass origin. In most savannah plots,
mixtures of grass and tree phytoliths were observed, and in most forested plots tree or
other unclassified types of phytoliths predominated. However, three plots did not follow
this pattern. Plot 2-2 was forested but contained predominately grass phytoliths. Plots
2-5 and 4-6 were savannah but contained essentially no tree phytoliths.

DISCUSSION

The pattern of fires on our transects indicates that there were three types of fires at
Devils Tower. By far the most common type of fire was the spot fire, caused by light-
ning, that affected one or only a few trees. These fires were either extinguished by rain-
fall or there was insufficient ground fuel for them to spread. They are evident on all of

TABLE 3. — Soil-borne opal phytoliths from different vegetation types

Transect and plot number	Phytolith content (% by weight)	Vegetation type
1-1	1.10	Prairie
1-2	0.94	Savanna oldest trees 82-140
1-3	0.81	Savanna oldest trees 86-145
1-4	0.97	Prairie
1-5	1.07	Prairie
1-6	0.57	Forest oldest trees 92-202
1-7	0.46	Forest oldest trees 106-213
2-1	1.08	Prairie
2-2	0.77	Forest oldest trees 74-76
2-3	0.49	Forest oldest trees 229
2-4	0.99	Prairie
2-5	0.83	Savanna oldest trees 44-47
2-6	0.55	Forest oldest trees 191
4-1	1.13	Prairie
4-2	0.89	Savanna oldest trees 91-125
4-3	0.49	Forest oldest trees 194
4-4	1.03	Prairie
4-5	1.08	Prairie
4-6	0.94	Savanna oldest trees 44-58
4-7	1.11	Prairie
4-8	0.54	Forest oldest trees 205
5-1	0.39	Forest oldest trees 274
5-2	0.96	Prairie
5-3	0.53	Forest oldest trees 178
5-4	0.98	Prairie

our transects, but are most common in the immediate area of the Tower. Trees on the Monument record many fires during the past two or three decades that are not recorded on the Monument's fire log. This is undoubtedly due to the localized nature and short duration of this type of fire.

The second type of fire that occurred was the local fire. These may have been lightning fires that spread to encompass a considerable area downwind from the origin or they may have been fires that have burned into the area and died out either due to weather conditions or lack of fuel. Five such fires entered the Monument either from the NW or SW, burned up to the Tower and died out in the rocky talus areas.

The third type of fire was the area-wide fire. These may have started on the Monument and grown to encompass the entire area. More likely, they entered the Monument after starting or having been started elsewhere. Fire scars most commonly form on the leeward side of the tree, and the great majority of fire scars on the Monument are on the NE or E side of the tree. This suggests that fires moved through the area from W to E.

As expected, the fire return period became longer after European settlement and the advent of fire suppression. The last area-wide fire was in 1937 and there have been only two area-wide fires since 1890. The 2- to 2.5-fold increase of the return period is not unlike that reported for other areas in the West.

The sharp increase in fire frequency between 1770 and 1900 was unexpected. This period coincided with a time during which the Sioux took possession of the Black Hills from the Cheyenne, Kiowa and Crow. The Sioux entered the Black Hills area about 1765 and by 1823 they controlled the area S of the Missouri from the Black Hills to the Bighorn Mountains (Grinnell, 1956; Hassrick, 1964). These early plains Sioux were displaced woodland people. They did not have many horses and did not know how to use those they possessed effectively in warfare or hunting (Grinnell, 1956). In the prairie-forest border area from which the Sioux had recently migrated fire was widely used to drive game.

There are few reports on the habits of the newly arrived Sioux in the Black Hills. We can only surmise that they continued to live in the forest as much as possible. They certainly would have quickly begun to hunt the buffalo. Again we can only surmise that they used the eastern woodland method of driving the animals into a river or over a break into a gully by means of fire. If either or both of these suppositions is true, it would help to account for the increase in fire frequency.

The warfare between the tribes, and later between the Sioux and Europeans, may have been enough to account for the increase in fires (Ewers, 1975). Before the Sioux migration, the northern plains away from the major rivers were sparingly used by the native people. The Sioux brought a population explosion to the area and dramatically increased use of minor streams such as the Belle Fourche River (Hassrick, 1964). This increased human occupation of the area may have also been a factor in the increased frequency of fires.

TABLE 4. — Differences in mean phytolith content of soils from the 0-15 cm depth in the three dominant vegetation types

Vegetation type	Phytolith content	
	Mean	Standard error
Prairie	1.05**	0.018
Savanna	0.88 ^b	0.027
Forest	0.53 ^c	0.035

*Values not followed by the same letter are significantly different at the .05% probability level using a t-test for unpaired observations with unequal variance

area of the Tower. Three decades that due to the localized fire. These may have been downwind from the area and died out either the Monument. In the rocky talus area may have started on the slopes, they entered the area most commonly in the scars on the Monument and through the area.

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and 1900 was unexpected possession of the area. The Black Hills of South Dakota from the Black Hills. These early plains Siouan tribes and did not know of fire (Grinnell, 1956). In the early days, fire was

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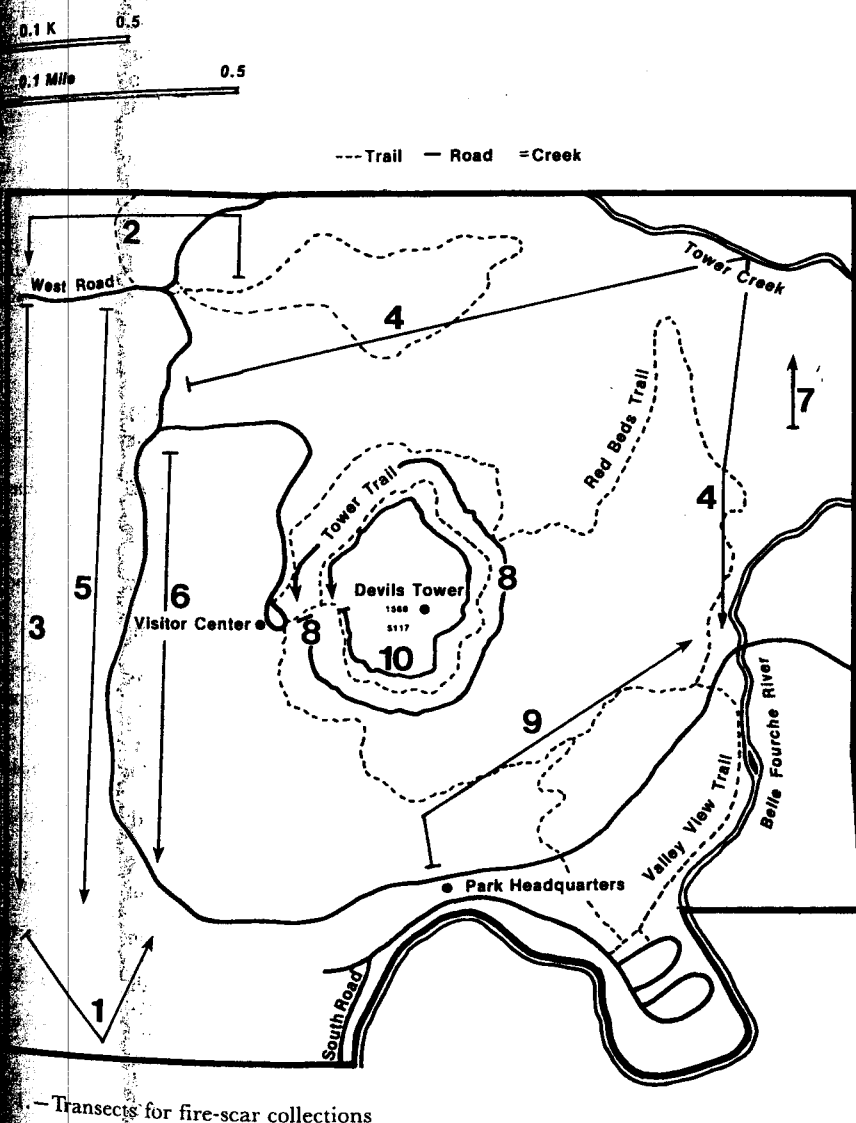
the Sioux and Euro- (Ewers, 1975). Before the 1800s, the area was sparsely settled. The area and the river (Hassrick, 1968) have been a factor in the

from the 0-15 cm

Phytolith content	Standard error
0.018	
0.027	
0.035	

percent at the 0.05% probability level

Opal-phytolith data help substantiate a picture of the Monument before fire as an area of open forest and savanna with expansive areas of prairie. Not only produce opal phytoliths that are significantly different in shape from those produced by trees, but they also produce many more phytoliths than trees. Thus grassland have significantly higher phytolith contents than areas of forest. Of areas of savanna have both trees and grasses and thus have intermediate phytolith content. Our data indicate that the Monument has had areas of stable forest, prairie, and savanna for hundreds if not thousands of years. The stable forest has existed in the broken terrain near the Tower and on protected slopes and in the bottoms of draws or gullies elsewhere on the Monument. These are areas where the lack of



ground vegetation to provide fuel or moist understory conditions would protect the forest against fire.

The savanna in general formed a band between the forest and the grassland. This savanna was not only kept open and parklike by frequent, light surface fires, but its extent was controlled by these frequent fires. After a fire the savanna and adjoining prairie are both ideal seedbeds for the establishment of new ponderosa pine. If seed is available and weather conditions are favorable, the area will become a forest of young tree seedlings. This will happen only infrequently because the chances of a fire, seed crop and favorable weather conditions occurring simultaneously are small.

Old ponderosa pine are quite fire-tolerant, but young seedlings are not. In order for this new forest to become established, a long period without fire is necessary. However, the grasses will also regenerate following the fire. New fuels will begin to build up and new fires will occur. If those fires occur every 10-20 years, the slow-growing ponderosa pine will not form a new forest. Some trees may become large enough to withstand fire and a few may escape due to the distribution of fuels or the whims of nature. Occasionally, a very few new trees become firmly established and the savanna becomes more dense or extends into the grassland.

This is a slow process at best and, prior to fire prevention, the prairie-forest mosaic at Devils Tower seems to have been stable. The savanna was probably more open and the prairie area somewhat larger than prior to 1770 because the mosaic was in equilibrium with a 14-year fire return period rather than the 27-year return period prior to 1770. After 1900, the fire return period dramatically lengthened. This has resulted in the area of prairie diminishing and the savanna becoming more dense, even becoming forest in some areas (plot 2.2, Table 4).

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