



Phytolith Evidence for the Lack of a Grass Understory in a Giant Sequoia (Sequoiadendron giganteum) Stand in the Central Sierra Nevada, California: A Report to Save-the-Redwoods League

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1 PHYTOLITH EVIDENCE FOR THE LACK OF A GRASS UNDERSTORY IN A
2 GIANT SEQUOIA (*SEQUOIA DENDRON GIGANTEUM*) STAND IN THE
3 CENTRAL SIERRA NEVADA, CALIFORNIA

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1 KEY WORDS: *Sequoiadendron giganteum*; phytoliths; fire regime; California
2 grasses; California paleoecology;

3 **Abstract**

4 Tree ring fire-scars in giant sequoia (*Sequoiadendron giganteum*) stands
5 record a high frequency, low intensity prehistoric fire regime. Difficulties
6 achieving short prehistoric fire return intervals with prescribed burns at a giant
7 sequoia stand in Calaveras Big Trees State Park, California, currently
8 characterized by dense tree cover with little understory vegetation due to over a
9 century of fire suppression, suggest that a prehistoric grass understory provided
10 fine fuel required for frequent fire spread. We used phytolith analysis to test this
11 hypothesis. Phytoliths, microscopic silica bodies found in many plants but
12 produced in large quantities with distinctive morphotypes in grasses, are
13 preserved for thousands of years in the soil. Soils under vegetation with
14 extensive prehistoric grass cover retain a high concentration of grass phytoliths
15 regardless of historic vegetation changes. Phytoliths were extracted from soil
16 samples taken from pits dug at 14 plots throughout a giant sequoia stand in the
17 South Grove Natural Preserve. Soil phytolith weight for most plots, currently
18 without grass cover and comprising most of the stand, was less than 0.10%,
19 consistent with reported values for forests with no grass in the understory. Soil
20 phytolith weights for ridge-top plots and plots near the stream channel were
21 significantly higher, suggesting localized areas with sparse grass cover. The
22 hypothesis that grass was a significant understory component in this giant
23 sequoia stand was rejected.

1 Introduction

2 Fire is an important ecosystem process in giant sequoia (*Sequoiadendron*
3 *giganteum*) stands in the central Sierra Nevada in California. Giant sequoia
4 appears to be dependent upon ground fires for regeneration in many areas.
5 Cones open following fire to release seeds; a few years following ground fire,
6 newly germinated giant sequoia seedlings dominate burned areas (Kilgore 1973;
7 Parsons and DeBenedetti 1979; Mutch and Swetnam 1995). Analyses of tree-
8 ring fire-scars from living trees and stumps in the Sierra Nevada indicate that
9 prior to the mid-1800s there was an average surface fire return interval of
10 approximately 5 years in giant sequoia stands of the mixed-conifer forest type
11 (Swetnam 1993; Caprio and Swetnam 1995; Parsons 1995). These surface fires
12 occurred in a patchy, mosaic pattern, and because crown fires involving giant
13 sequoia were evidently rare (judging from the presence of trees in excess of
14 1500 years old), caused little mortality to large giant sequoias. Frequent low
15 intensity ground fires were probably important for forest health and maintained
16 giant sequoia groves in open, park-like stands.

17 From about 1860 to 1900, natural ecosystem processes in giant sequoia
18 stands, including fire, were drastically altered by livestock grazing (mainly
19 sheep), cessation of aboriginal burning practices, limited logging, and
20 suppression of natural or human-caused wildfires (Kilgore and Taylor 1979).
21 Currently, many mixed conifer forest stands at Calaveras Big Trees State Park
22 are thickets of mid-sized trees, often dominated by white fir (*Abies concolor*) and
23 incense cedar (*Calocedrus decurrens*). There is little understory vegetation

1 because the overstory canopy is almost closed and provides little opportunity for
2 light to reach the forest floor. The conditions wherein giant sequoia stands can
3 self-perpetuate and flourish no longer exist.

4 Based on tree-ring analysis, from 500 to 1900 the longest recorded period
5 without a fire in a giant sequoia stand was approximately 60 years, while during
6 centuries with high fire frequencies (generally periods of drought) the longest
7 non-burn interval per stand was typically no more than 13 years (Swetnam
8 1993). There are currently some giant sequoia stands that have had no fire for
9 the past 100 years.

10 Prescribed fire has been introduced into giant sequoia stands in many
11 parks in the Sierra Nevada, including Calaveras Big Trees State Park, as a
12 means of restoring more natural conditions. Ground fires have typically been set
13 under proper conditions in late summer or fall with goals of removing excessive
14 fuels, killing invading fir and cedar trees, and restoring natural processes.
15 Experience has revealed that for up to 15 years following initial prescribed
16 burning, the understory vegetation and overstory canopy conditions will not
17 support extensive surface fires. Maintaining a fire return interval of 5 years has
18 not been possible because not enough fuel is available to adequately carry
19 surface fire throughout giant sequoia stands. Based on tree ring fire-scar
20 evidence of fires occurring on average every 5 years, it appears there must have
21 been either different overstory species, such as deciduous hardwoods,
22 contributing fuel to the forest floor, or understory shrubs, herbs, or grasses that
23 grew more densely and provided fuel for frequent fires.

1 The precise structure of pre-1850 giant sequoia stands, particularly the
2 composition and biomass of understory plant species, is unknown (Vankat and
3 Major 1978; Stephenson 1996; Stephenson 1999). In the 1860s, livestock
4 grazing, principally large flocks of sheep, was introduced into the central Sierra
5 Nevada (Swetnam 1993; Kilgore and Taylor 1979), suggesting there was a
6 substantial amount of forage available. Researchers in many areas of the
7 western United States, particularly the monsoonal southwest, have found that
8 fine fuels were important for the spread of ground fires, and that removal of these
9 fuels by livestock beginning in the mid-1800s probably led to sharp declines in
10 fire frequency (Swetnam et al. 1990; Caprio and Lineback 2002).

11 Prior to alteration of natural fire regimes in the mid-1800s, giant sequoia
12 and mixed conifer stands in the vicinity of Calaveras Big Trees State Park were
13 probably composed of widely spaced, large diameter, towering giant sequoia, a
14 few sugar pine (*Pinus lambertiana*) and ponderosa pine (*Pinus ponderosa*), and
15 a lesser element of white fir and incense cedar. These stands were probably
16 devoid of dense woody understory vegetation because of frequent surface fires
17 ignited by native people or lightning. Some researchers believe the open nature
18 of these stands allowed sufficient sunlight to reach the forest floor to support an
19 understory of native grass species, which during the dry season served to carry
20 frequent surface fires throughout the forest stand. The surface fires killed most
21 small shrubs and trees, removed smothering duff layers, recycled nutrients,
22 perpetuated the grass-dominated understory vegetation, and maintained gaps in

1 the stands for forest regeneration. Unfortunately, little solid evidence exists
2 either way regarding the existence of this prehistoric grass understory.

3 We used phytolith analysis to test the hypothesis that grasses were an
4 important prehistoric component of the understory of giant sequoia stands. Opal
5 phytoliths are microscopic particles of silica formed in the cells of many plants
6 and released into the soil during decomposition (Piperno 1988). Phytoliths are
7 highly resistant to weathering and in many soil environments will persist for
8 thousands or even millions of years (Wilding 1967; Strömberg 2004). Grasses
9 produce many more phytoliths than most other plant taxa, averaging 3% dry
10 weight phytolith content (Witty and Knox 1964). Consequently, soils formed
11 under grassland vegetation contain an order of magnitude more phytoliths (1-3%)
12 than soils formed under forest vegetation with few grasses (Witty and Knox 1964;
13 Jones and Beavers 1964; Wilding and Drees 1968; Norgren 1973; Miles and
14 Singleton 1975). Phytoliths take the shape of the cell in which they are formed.
15 Most phytolith shapes are produced by many different plant taxa, but a few taxa
16 produce distinctive phytolith morphotypes (Rovner 1971). Grasses produce
17 bulliform, trichome, and short cell phytoliths that are diagnostic of the Poaceae
18 family. Short cell phytoliths, including rondels, bilobates, saddles, and crenates,
19 have been used to identify grasses to the subfamily level (Twiss et al. 1969;
20 Twiss 1992; Mulholland and Rapp 1992).

21 Several studies have used soil phytoliths to document changes in
22 dominant vegetation over time. In the prairie peninsula in Illinois, Wilding and
23 Drees (1968) used large differences in soil phytolith content to identify areas of

1 prehistoric forest, grassland, and the forest-grassland ecotone. In Utah, Fisher et
2 al. (1995) used changes in soil phytolith assemblages to document a shift from
3 grassland to shrubland with the introduction of grazing. Bartolome et al (1986),
4 working at Jepson Prairie in the California Central Valley, used changes in the
5 concentration of bilobate grass phytolith shapes with soil depth to infer a
6 prehistoric shift from *Nassella*-dominated perennial grassland to the exotic
7 annual grassland present today. Bicknell et al. (1992, 1993) used soil phytolith
8 concentration to map the extent of prehistoric grasslands at several state parks in
9 coastal California, finding many currently forested areas were grasslands prior to
10 European settlement and many current grasslands were previously forested. In
11 northern Arizona, the soil phytolith assemblage from a ponderosa pine forest with
12 a bunchgrass understory was analyzed to determine the long-term stability of the
13 current vegetation (Kerns 2001; Kerns et al. 2001; Kerns et al. 2003). High
14 concentrations of pine and grass phytoliths in soil surface and subsurface
15 samples indicated little change over time. All of these studies have shown that if
16 there was substantial prehistoric grass cover on a site, there will be a high
17 concentration of grass phytoliths in the soil.

18 **Site Description**

19 The study area is located in the South Grove Natural Preserve of
20 Calaveras Big Trees State Park, 200 km east of Stockton, California (Figure 1).
21 The park is 2,625 ha with an elevation range from 1000 m to 1700 m.
22 Topography is dissected, with a western slope overall, and NE-SW trending
23 ridges between steep river canyons. The climate of the western Sierra Nevada is

1 distinctly seasonal and highly influenced by elevation. The annual precipitation
2 at the elevation of the park ranges from 100 to 170 cm, much of it coming as
3 snow. About 90% of the total precipitation occurs during the six month period
4 between November and April (Walfort and Hunt 1982).

5 Soils in the South Grove Natural Preserve (Figure 2) are dominated by the
6 McCarthy series, inceptisols characterized as gravelly sandy loam/very gravelly
7 sandy loam found on slopes of 5 to 60%. Soil pH ranges from 6.3 at the surface
8 to 5.9 at 60 cm depth. Parent material is well-drained, basic, volcanic rock with
9 rapid permeability.

10 Overstory vegetation at Big Trees is largely pine/mixed pine and fir forest
11 dominated by ponderosa pine (*Pinus ponderosa*), sugar pine (*Pinus*
12 *lambertiana*), and white fir (*Abies concolor*) in either pure or mixed stands.
13 Incense cedar (*Calocedrus decurrens*), California black oak (*Quercus kelloggii*)
14 and canyon live oak (*Quercus chrysolepis*) also occur within the park. Vascular
15 plants that have been identified in the park include over 60 families, 159 genera
16 and 219 species (Walfort and Hunt 1982). Common species are listed in Table
17 1.

18 The giant sequoia (*Sequoiadendron giganteum*) stands of the park are
19 located in two groves, designated the North and South Groves. In the never-
20 logged South Grove, giant sequoia comprises 65.9% of the total basal area
21 followed by white fir at 21.7% (Walfort and Hunt 1982). Grass cover is very
22 sparse throughout the grove, with maximum 5% cover in patches near the top of
23 the watershed's north ridge.

1 **Methods**

2 To better understand the soil phytolith assemblage, a phytolith reference
3 collection, composed of phytoliths extracted from leaf samples from all major
4 plant species currently present in the study area (Table 1), was assembled.
5 Phytoliths were extracted using a modified dry ashing technique (Piperno 1988;
6 Pearsall 1989; Kondo et al. 1994). Samples were washed in distilled water to
7 remove adhering minerals, rinsed in 10% HCl to improve combustion, ashed in a
8 muffle furnace at 550°C for 4 hr, rinsed again in 10% HCl to remove acid-soluble
9 residue, washed 3 times in water, and dried in ethanol. To view phytoliths, dry
10 residue was resuspended in immersion oil so that phytoliths could be rotated and
11 3-dimensional characteristics observed, mounted on a slide, and viewed under a
12 phase-contrast light microscope at 400X. Two slides for each plant were
13 scanned completely and potentially diagnostic phytolith types noted.

14 Soil samples were collected from soil pits dug on 14 plots (Figure 2).
15 Plots were selected to span the topographic gradient of the watershed,
16 particularly but not exclusively in locations currently occupied by giant sequoia.
17 To assess within plot variation in soil phytoliths, two pits within 100 m of each
18 other were dug and sampled at each plot. Phytolith samples from both pits were
19 processed and counted for plots that had >0.10% soil phytoliths; otherwise,
20 samples from only one pit were processed. Soil samples were collected from
21 each pit at five depths: mineral soil surface, 10 cm, 25 cm, 40 cm, and 55 cm.
22 Phytoliths were extracted from 5 g soil samples by standard procedures:
23 deflocculation in Calgon, HCl wash, organic matter digestion in 30% hydrogen

1 peroxide, heavy liquid flotation in zinc bromide at specific gravity 2.30, mount on
2 slides as above (Carbone 1977; Kondo et al. 1994). Because the biogenic silica
3 residue contained diatoms and residual mineral silica particles, phytolith weight
4 for each sample was estimated by examining 10 microscope fields on a slide,
5 estimating the percentage of non-phytolith material, and subtracting this
6 percentage from the measured residue weight (Carnelli et al. 2001). Phytolith
7 morphological types were tallied for each soil sample until 400 were counted.
8 The percentage of diagnostic grass phytoliths (long cells, trichomes, bulliforms,
9 and short cells) to total phytoliths in each sample was calculated.

10 **Results**

11 Extracted reference material from most plant species contained small
12 amounts of poorly silicified biogenic silica but no diagnostic phytoliths (Table 1).
13 Ponderosa pine was the only tree species with diagnostic phytoliths: spiny bodies
14 and spiny rods (Norgren 1973; Kerns 2001) were isolated from needles in
15 substantial amounts. No shrubs contained diagnostic phytoliths. Sedges
16 produced long cells and diagnostic conical phytoliths (Ollendorf 1992). All
17 grasses contained abundant phytoliths, including long cells, trichomes,
18 bulliforms, and short cells (Twiss et al. 1969; Twiss 1992). *Achnatherum*,
19 *Danthonia*, and *Melica* were the only grasses sampled producing bilobate short
20 cells. Other grasses produced abundant rondel short cells.

21 Soil phytolith weight averaged less than 0.55% on all plots (Table 2), but
22 varied according to topographic position in the watershed. Hillside plots (Figure
23 2: Plots 1-7, 11, 12), typical of most of the sampled watershed, had very low soil

1 phytolith concentration (<0.10%) at all depths. Plots on or near the ridge (Plots
2 8-10), where ponderosa pine was present in the overstory, contained significantly
3 more soil phytoliths (mostly ponderosa pine spiny bodies) at all depths than
4 hillside plots. Plots in the lower part of the watershed within <50 m of the stream
5 channel (Plots 13, 14), where no ponderosa pine was observed in the overstory,
6 also contained significantly more soil phytoliths than hillside plots.

7 All plots contained diagnostic grass phytoliths, but topographic position
8 influenced grass phytolith percentages (Table 2). Hillside plots had the lowest
9 percentage of grass phytoliths; channel-side plots had significantly more grass
10 phytoliths than either of the other topographic positions. Extremely few bilobate
11 phytoliths were found, indicating none of the bilobate-producing grasses,
12 *Achnatherum*, *Danthonia*, and *Melica*, had significant prehistoric cover on any of
13 the plots.

14 **Discussion**

15 Grassland soils have been found by various researchers to contain at
16 least 5-10 times more phytoliths by weight than forest soils, which generally have
17 phytolith content between 0.1 and 0.5% by weight (Witty and Knox 1964; Jones
18 and Beavers 1964; Wilding and Drees 1968; Norgren 1973; Miles and Singleton
19 1975; Bicknell et al. 1992; Bicknell et al. 1993). The ponderosa pine-bunchgrass
20 type in northern Arizona (~50% grass cover in the understory), probably the
21 closest phytolith analog for Sierra Nevada mixed conifer forests if they had a
22 prehistoric grassy understory, showed total phytolith content of 1-2.5% (Kerns
23 2001; Kerns et al. 2001; Kerns et al. 2003). Grass phytoliths made up

1 approximately half of the total, ponderosa pine the other half (B. Kerns, personal
2 communication).

3 Phytolith concentration on hillside plots in our study was at the low end of
4 published data, even for forest plots. The paucity of phytoliths observed in the
5 reference material suggests that unless ponderosa pine, grasses, or sedges
6 were present on the plot for a substantial period of time in the past, very few
7 phytoliths were deposited in the soil.

8 Ridge-top plots had phytolith concentrations within the expected range for
9 forest soils, but considerably less than found at the ponderosa pine-bunchgrass
10 site in northern Arizona. Ponderosa pine and bunchgrasses are currently minor
11 components of the vegetation on these plots; grasses (mostly *Bromus carinatus*
12 and *Elymus elymoides*) are present with <5% cover. The phytolith evidence
13 suggests that ponderosa pine and bunchgrasses were prehistorically present but
14 have remained minor components of ridge-top vegetation.

15 Lower channel-side plots had higher grass phytolith concentration than
16 expected for forest soils but less than half the concentration typical of grassland.
17 There are currently very few grasses in this part of the watershed. One possible
18 explanation is that there was a prehistoric stringer meadow associated with the
19 stream that disappeared when the water table dropped. Phytolith sampling of a
20 small stringer meadow in the mixed conifer forest in the Sierra San Pedro Martir
21 in Baja California found total phytolith weight and percentage of grass phytoliths
22 comparable to these plots (R. Evetts, unpublished data).

1 Phytolith migration and dissolution, alternative explanations for low soil
2 phytolith weights, must be ruled out before the grass understory hypothesis can
3 be rejected. Because they are mostly silt-sized particles, phytoliths are known to
4 migrate downward in the soil profile, particularly in sandy soils (Starna and Kane
5 1983). Sampling at several depths in soil pits revealed no evidence of
6 significantly fewer phytoliths at the surface or accumulation of phytoliths at any
7 depth (Table 2). Phytolith degradation and dissolution is known to occur under
8 alkaline soil conditions but only under the most severe acidic conditions (Piperno
9 1988). The main soil type sampled, the McCarthy series, is slightly acidic (pH
10 6.3-6.4) (Walford and Hunt 1982), ideal conditions for soil phytolith preservation.
11 Phytolith migration and dissolution are not plausible explanations for the lack of
12 grass phytoliths in South Grove soils.

13 In the absence of phytolith migration, it is reasonable to expect increasing
14 phytolith age and decreasing phytolith concentration with increasing soil depth
15 (Piperno 1988). Although no dating was attempted (and would be difficult to
16 interpret because of bioturbation issues), phytoliths from each sampled soil
17 profile probably span at least the past 1500 years, the age of the oldest living
18 giant sequoias in the stand, but more likely several thousand years.

19 The phytolith evidence strongly indicates that grasses were not a
20 significant prehistoric component of the giant sequoia forests in the South Grove
21 Natural Preserve. We conclude that grass could not have been the source of
22 fine fuel required to carry frequent prehistoric ground fires in this giant sequoia
23 stand. Because none of the other plant species examined (except for sedges

1 and ponderosa pine) produced diagnostic phytoliths, the prehistoric presence of
2 small tree or shrub species in the understory could not be determined from
3 phytolith evidence.

4 Research in other giant sequoia stands supports this conclusion. Biswell
5 et al. (1966a) found that shrubs and herbaceous plants were abundant in early
6 successional stages of a giant sequoia stand, and that grasses and grass-like
7 plants (*Carex multicaulis*, *Bromus marginatus*, and *Festuca occidentalis*) were
8 the most frequent forest floor species following logging, though their frequency
9 was less than 10%. It appears that even under the best of circumstances,
10 extensive grass understory is rare in giant sequoia forests.

11 Mutch and Swetnam (1995) found that giant sequoia radial growth of large
12 trees often increased for 5 years or more following ground fires, suggesting the
13 trees were experiencing more favorable light, water, or nutrient conditions
14 following fire (some suppression of large tree radial growth was also found
15 possibly indicating burned foliage). If grass in the understory was the source of
16 fuel for regular burning, it is unlikely the overstory trees would have shown such
17 a pronounced and sustained response to fire. Grass would quickly re-grow in
18 burned areas, depriving the trees of any benefit of their removal. The tree growth
19 data implies grasses were not a factor in giant sequoia stands.

20 Stephens et al. (2003) studied mixed-conifer forests in the Sierra San
21 Pedro Martir (SSPM), Mexico. These forest stands, dominated by pine species,
22 have been largely undisturbed by logging or fire suppression and are considered
23 the southern extreme of the California Floristic Province (though without giant

1 sequoia). They found the mean fire return interval since 1700 varied among their
2 stands from 3.9-23.5 years. There was an increase in fire return interval in these
3 stands beginning about 1800, which they attributed to construction of a mission
4 that introduced livestock grazing and disrupted aboriginal burning practices. The
5 mean fire interval increased 6.8 years (6.6 ± 2.1 years in the 1700s versus 13.4
6 ± 5.8 years in the 1800s). They speculated that the effect of grazing on grass
7 understory was probably severe but sufficient fuel was present in many years to
8 still carry lightning-caused ground fires. They suggested that cyclical changes in
9 climate and decreased anthropogenic fire may have also contributed to
10 lengthening the fire interval. However, recent phytolith data from the SSPM
11 showed conclusively that grasses were not an important part of the prehistoric
12 forest understory, refuting the grazing hypothesis for observed changes in fire
13 return intervals (R. Evetts, unpublished data).

14 Parsons (1978) found at Redwood Mountain (approximately 100 km south
15 of Calaveras Big Trees State Park and 550 m higher elevation) that forest floor
16 fuel loads following the first prescribed fire in a stand were similar to unburned
17 stands 7 years following burning; however, he attributed much of this fuel to
18 material killed by the prescribed fire from white fir that had invaded the giant
19 sequoia stands during the past 100 years when fire was absent. Parsons
20 predicted that a second prescribed fire would remove this fuel source; it was
21 unclear where additional fuel to support a short fire interval would come from. It
22 is possible that deciduous hardwoods co-occurring with giant sequoia provided
23 sufficient surface fuels prior to the mid 1800's to achieve an average 5 year fire

1 interval. As a result of livestock grazing and the altered fire situation for the past
2 150 years, hardwoods such as black oak (*Quercus kelloggii*) are now uncommon
3 in giant sequoia stands (Biswell et al. 1966a, Bonnicksen and Stone 1982).
4 Further research is necessary to investigate the possibility of hardwood as a fuel
5 source.

6 Parsons (1995) stated that fire in giant sequoia stands stimulated shrub
7 and hardwood growth. The patchy nature of natural fires, with irregular shapes
8 and varying rate of spread, and role of occasional intense fires (Stephenson et al.
9 1991) provides opportunity for shrubs to provide a significant amount of fuel.
10 Common shrubs in the vicinity of giant sequoia stands include mountain misery
11 (*Chamaebatia foliolosa*), buckbrush (*Ceanothus cuneatus*), deerbrush
12 (*Ceanothus integerrimus*), and bush chinquapin (*Chrysolepis sempervirens*). Of
13 these, mountain misery seldom occurs in giant sequoia stands and would be
14 displaced by frequent burning. *Ceanothus* species are known to invade areas
15 following disturbance but have never been commonly found within giant sequoia
16 stands. Bush chinquapin burns well but is typically only dense on north facing
17 slopes. Because phytolith analysis provides no information on these shrubs,
18 resolving the question of their abundance in giant sequoia stands remains
19 problematic.

20 There are a couple of possible explanations for the current lack of success
21 achieving fire return intervals of 5 years with prescribed burning. First, there may
22 be sufficient litter on the forest floor after 5 years to carry a fire under extreme
23 conditions. Biswell (1966b) found that giant sequoia produced large amounts of

1 litter each year, ~ 9,000 lbs/acre. Prescribed burning is normally attempted only
2 under safe weather conditions according to the prescription. A 5 year
3 accumulation of giant sequoia litter should be enough to carry a patchy fire, but
4 only under extreme conditions not allowed by the prescription, such as very low
5 humidity, high temperatures and high winds. Many of the fires seen in the tree-
6 ring record may have been set by humans whenever extreme conditions were
7 present, without concern for catastrophic fires because they knew the intensity
8 would be very low.

9 Second, given the short prehistoric fire return interval and more widely
10 spaced trees, litter build-up was probably very uneven on the forest floor,
11 leading to highly patchy, low intensity fires. This has been observed in mixed
12 conifer forests in the Sierra San Pedro Martir, where forest structure remains
13 relatively open because of a continuing fire regime (Stephens et al. 2003). The
14 fire return interval, usually estimated by calculating how often fires scar >25% of
15 the recording trees in a stand, may not be very useful in a highly patchy
16 environment. Even though 25% of the stand burns in a given year and is
17 counted as a fire year in fire return interval calculations, there may be 75% of the
18 stand that does not burn that year. A fire may not burn throughout the stand
19 every 5 years; it may take 15 or 20 years to burn every part of the stand. A
20 better measure in this patchy situation may be the fire rotation period, defined as
21 the average length of time between fires averaged for each fire-scar recording
22 tree (Baker and Ehle 2001). This gives an estimate of the maximum time
23 required to burn an area the size of the stand, and may more accurately

1 represent temporal burning patterns in giant sequoia stands. If this is true,
2 expecting a prescribed fire to burn through an entire stand every 5 years may be
3 unrealistic.

4 The management goal for Calaveras Big Trees State Park is to ensure
5 natural processes are the principal influence on giant sequoia stands so that
6 large, exceptional specimens can grow to maturity and the species can
7 regenerate naturally. Current forest conditions, because of past logging and fire
8 suppression, have created an environment wherein giant sequoia does not
9 regenerate naturally because of a lack of surface fire, and large mature trees are
10 at risk from catastrophic crown fires carried by the tightly crowded thickets of fir
11 and pine trees that have developed in the absence of surface fires. Through
12 phytolith analysis, an inexpensive approach to definitively test for the presence of
13 prehistoric grass, we have shown that the prehistoric frequent fire regime at
14 South Grove Natural Preserve did not depend on a grass understory. Grass
15 should not be part of management strategies seeking to mimic prehistoric fire
16 regimes. The South Grove is typical of other giant sequoia stands in the central
17 Sierra Nevada. The results of this study, if replicated at other locations, may be
18 applicable to giant sequoia fire management in a much wider region.

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Table 1. Species present in Calaveras Big Trees State Park and sampled for phytolith reference collection with observed diagnostic phytolith morphotypes.

| Species | Common name | Diagnostic morphotypes |
|---------------------------------|-----------------------|------------------------------------|
| Trees | | |
| <i>Abies concolor</i> | white fir | none |
| <i>Acer macrorphyllum</i> | big-leaf maple | none |
| <i>Alnus rhombifolia</i> | white alder | none |
| <i>Calocedrus decurrens</i> | incense cedar | none |
| <i>Cornus nuttallii</i> | dogwood | none |
| <i>Corylus cornuta</i> | California hazelnut | none |
| <i>Pinus lambertiana</i> | sugar pine | none |
| <i>Pinus ponderosa</i> | ponderosa pine | spiny bodies, spiny rods |
| <i>Pseudotsuga menziesii</i> | Douglas-fir | none |
| <i>Quercus kelloggii</i> | black oak | none |
| <i>Sequoiadendron giganteum</i> | giant sequoia | none |
| Shrubs | | |
| <i>Ceanothus cordulatus</i> | mountain whitethorn | none |
| <i>Ceanothus integerrimus</i> | deer brush | none |
| <i>Chamaebatia foliolosa</i> | mountain misery | none |
| <i>Chimaphila umbellata</i> | pipsissewa | none |
| <i>Chrysolepis sempervirens</i> | bush chinquapin | none |
| <i>Rhododendron occidentale</i> | western azalea | none |
| <i>Rosa pinetorum</i> | pine rose | none |
| <i>Rubus parviflorus</i> | thimbleberry | none |
| <i>Ribes roezlii</i> | Sierra gooseberry | none |
| <i>Symphoricarpus mollis</i> | snowberry | none |
| Herbs | | |
| <i>Adenocaulon bicolor</i> | trail plant | none |
| <i>Aquilegia formosa</i> | crimson columbine | none |
| <i>Asarum hartwegii</i> | wild-ginger | none |
| <i>Carex</i> sp. | sedge | conical cells |
| <i>Clintonia uniflora</i> | bride's bonnet | none |
| <i>Fragaria vesca</i> | wood strawberry | none |
| <i>Galium aparine</i> | goose grass | none |
| <i>Hieracium albiflorum</i> | hawkweed | none |
| <i>Iris hartwegii</i> | Hartweg's iris | none |
| <i>Lonicera involucrata</i> | twinberry | none |
| <i>Lupinus</i> sp. | lupine | none |
| <i>Phacelia</i> sp. | phacelia | none |
| <i>Pyrola picta</i> | white-veined shinleaf | none |
| <i>Smilacina racemosa</i> | false solomon's seal | none |
| <i>Trientalis latifolia</i> | starflower | none |
| <i>Viola lobata</i> | pine violet | none |
| Grasses | | |
| <i>Achnatherum lemmonii</i> | Lemmon's stipa | short cells, trichomes, bulliforms |
| <i>Bromus carinatus</i> | California brome | bilobate short cells |
| <i>Danthonia unispicata</i> | one-spike oatgrass | rondel short cells |
| <i>Elymus elymoides</i> | squirreltail | bilobate short cells |
| <i>Festuca rubra</i> | red fescue | rondel short cells |
| <i>Melica aristata</i> | awned melic | rondel short cells |
| <i>Poa secunda</i> | one-sided bluegrass | bilobate short cells |

Table 2. Soil phytolith weight as a percentage of soil weight and percentage of total phytoliths with grass morphotypes in relation to soil depth and topographic position in the South Grove Natural Preserve, Calaveras Big Trees State Park.

| | Soil Depth (cm) | Soil | 95% t-value | Grass | 95% t-value |
|--------------------------------|--------------------|----------------------------|------------------------|-------------------|------------------------|
| | | Phytolith Weight (%) | Confidence Interval | Phytoliths (%) | Confidence Interval |
| Hillside plots (N=9) | Surface | 0.08 | 0.06–0.10 | 21 | 14–28 |
| | 10 | 0.04 | 0.03–0.05 | 17 | 12–22 |
| | 25 | 0.02 | 0.01–0.03 | 26 | 17–35 |
| | 40 | <0.01 | – | – | – |
| | 55 | <0.01 | – | – | – |
| Ridge-top PIPO plots (N=6) | Surface | 0.47 | 0.35–0.59 | 12 | 5–19 |
| | 10 | 0.36 | 0.24–0.48 | 12 | 10–14 |
| | 25 | 0.37 | 0.25–0.49 | 15 | 10–20 |
| | 40 | 0.32 | 0.15–0.49 | 11 | 1–21 |
| | 55 | 0.18 | 0.00–0.38 | 15 | 8–22 |
| Lower channel-side plots (N=4) | Surface | 0.31 | 0.25–0.37 | 43 | 37–49 |
| | 10 | 0.52 | 0.38–0.66 | 31 | 20–42 |
| | 25 | 0.53 | 0.39–0.67 | 38 | 30–46 |
| | 40 | 0.44 | 0.33–0.55 | 35 | 18–52 |
| | 55 | 0.43 | 0.35–0.51 | 42 | 28–56 |

- 1 List of Figures
- 2 Figure 1. Location of Calaveras Big Trees State Park and the South Grove
- 3 Natural Preserve, georeferenced in UTM.
- 4 Figure 2. Location of phytolith sampling plots in the South Grove Natural
- 5 Preserve, Calaveras Big Trees State Park, georeferenced in UTM.



