Wildfire Smoke Exposure: A Comparative Study Wildfire Smoke Exposure: a Comparative Study between Two Analytical...

Wildfire Smoke Exposure: a Comparative Study between Two Analytical Approaches; Particle Assemblage Analysis and Soot, Char and Ash Analysis

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ABSTRACT

The characterization of combustion particles is an essential part of establishing the presence of debris from a wildfire. That characterization is much more than identifying charred wood, soot, or black material. It involves the identification of the combustion products from the fuel. That includes characterizing the types of charred wood, phytoliths from the plants that made up the fuel, skeletonized cell structure of those plants in the ash, the burnt soil from the updrafts, and even aerosolized fire retardant. Forest, chaparral, and savannahs are not made up of one or two plant types but dozens of different plants. These all contribute to the smoke and form a signature for that fire. This signature forms the assemblage of particles marking the specific wildfire. This paper includes a comparison of two different approaches used to assess wildfire smoke exposure. One is based on the presence of black particles and the other is based on the unique assemblage of signature particles. Duplicate samples were taken and were sent to two different laboratories for analysis in one of the case studies shown here. In another case study proximity to major roads improperly correlated to an increase in the level of reported exposure to fire debris.

INTRODUCTION

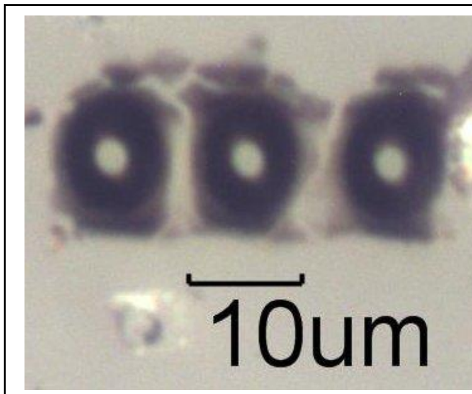
Correctly identifying exposure to wildfire smoke is critical to assessing the need and the extent of remediation that can be justified on an insurance claim. Millions of dollars are at stake for the insurance companies and tens of thousands of dollars are at stake for the home owner. Both parties need an accurate assessment of exposure to begin the process of negotiation. The first step in any assessment is the collection of samples. Where they are collected, how they are collected, and the medium used to collect them is important[1]. Ideally, this is done soon after the suspected exposure. In reality, this is often done months after the exposure. The particles identifying smoke from a specific wildfire have been identified in some cases as much as eighteen (18) months after exposure[2]. This would not have been possible without assemblage analysis[3].

Assemblage analysis is widely used in a number of scientific pursuits though it is not always called assemblage analysis. It's applied by medical doctors when they use symptoms to diagnose a health condition. The diagnosis is not made based on a single symptom but on a "suite" (assemblage) of symptoms that characterize an illness. It's used by petrologists to identify a probable oil-bearing rock formation[4,5]. It is used by paleontologists and archeologists to characterize ancient climates and identify ancient cultures[6,7]. It is also frequently used to assess water quality[8]. Assemblage analysis has many applications, including the characterization of environmental quality and the sources of contaminants in the environment[9,10,11,12,13]. Assemblage analysis is basically the use of multiple pieces of information to arrive at a conclusion not justified by any single component of the assemblage.

As an example, consider a family consisting of a man, a woman, and a child living together in a home. What is the assemblage? It would be a man and a woman of approximately similar age, the woman old enough to have a child of that age but not too old to have had that child. It would include the home and the proximity of the three individuals to one another and to the home. Toys in the yard consistent with the age of the child would increase the probability of association. Assemblage analysis is a Bayesian statistical approach to allocating the elements in an environment to a particular relationship or source. It is possible that the man, woman, child, and home, with their proximity was a coincidence. Even if the man and woman were kissing and holding the child that would only increase the probability of our assessment. It is still possible, though increasingly unlikely, that they are unrelated in any way. But what would be the probability of the appearance of a man on the street to assuming he was married, lived on this street, in that house, with his wife, and they had a child if no woman, child, or particular house seemed related to the man. The assemblage of facts makes a much stronger case for knowing how the man relates to this neighborhood. The same is true for charred wood.

Environmental Assemblage Analysis takes advantage of the fact that particle sources rarely generate a pure, single, particle type. It takes a lot of effort and is very costly to make a pure compound. It doesn't happen by accident. Emissions from processes tend to show how different materials exposed to that process are modified by that process.

In the case of a wildfire, leaves may be burned to white ash while wood is splintered and charred into black fibers or even carbon circles that used to be pores in the wood (Photograph 1). Grasses may be reduced to carbon darkened silica phytoliths. Whewellite phytoliths (CaC_2O_4-H_2O, calcium oxalate monohydrate) may be converted to calcium carbonate, then calcium oxide, and then back to calcium carbonate in the plume. Soil may go from colorless, tan, or slightly bluish to brick red. Each of these particles not only indicate a fire but the plants that were burning, what parts of the plants were burning, how hot the fire was, the weather being created by the fire, and how fast it was moving. This information is carried in the crystal structure, morphology, color, associations, and reflectivity of the particles. The



Photograph 1: Charred Pine Pores

crystal structure is not the shape, it is the optical crystallographic information only visible with polarized light. The morphology is the crystal habit, cellular alignment, pore structure, outline, texture, internal structure, and other features that relate to the outward and internal shape of the particle. Color is both the color with transmitted light and with reflected light. These colors may be very different. Associations relate to different phases in the same particle and to proximity of related particles. The reflectivity of char increases as the hydrogen in the particle decreases. The reflectivity may change with linear polarized light. The reflectivity also changes with increased crystallinity. These are not things that can be measured or detected with an electron microscope. Aerosolized fire retardant is another particle that is often found associated with the plume of a wildfire.

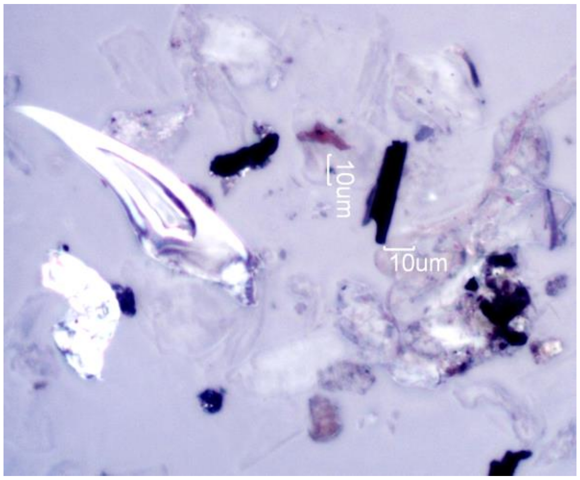
Light microscopy is particularly suited to this type of analysis. It is capable of analyzing a greater variety of particle types than any other single instrument. Thousands of particles can be characterized in a relatively short period of time as surface areas of a few square inches are examined. This capability will become evident as we consider the application of the light microscope to the assemblage analysis of wildfire emissions.

Environmental assemblage analysis using light microscopy in the case exposure to wildfire smoke can only be performed on tapelifts. Tapelifts are 95% efficient at collecting particles down to one micrometer. They collect fragile particles and retain vital particle associations. Tapelifts reliably represent the area sampled. That allows for dependable quantification. Wipe samples destroy these associations and pulverize delicate particles. Wipes are about 75% efficient at collecting particles from a surface resulting in a poorly defined surface area[1]. For analysis the particles must be removed from the wipes which presents another sampling dilemma; some particles are easily removed and others are more difficult. Consequently, wipe samples have very little value for this type of particle analysis.

METHODS

The assessment of smoke exposure has two parts. The first is identifying the presence of smoke debris from the suspect fire. The second is the quantification of that exposure. Both of these separate parts of the analysis are quite different using "Assemblage Analysis" compared to the "Soot, Char, and Ash Analysis" method used by many laboratories for this purpose.

Assemblage analysis has been used as a major tool to identify the source of airborne particles for since the time of Robert Hooke in the second half of the 1600's. It has been an important part of urban air pollution studies since Hooke's time. In the 1960's through the 1980's it was applied by the United States Environmental Protection Agency (EPA) and by Department of Ecology in the United Kingdom to identify the sources of urban and indoor air pollution. It was during the EPA studies of the 60's and 70's that charred wood from fireplaces was first identified as a major source of urban air pollution. This shouldn't have been much of surprise since peat burning space heaters were identified as a major cause of polluted air in London during the reign of Edward the Second at the beginning or the 1300's. Assemblage analysis was used by the National Air and Space Agency (NASA) in the United States to identify sources of contamination on space craft to better control the cleanliness of optics in orbit and for deep space probes. References were all cited in the introduction. The application of assemblage analysis to assess wildfire smoke exposure is an easy extension of this methodology.



Photograph 2: House Tapelift, No Fire

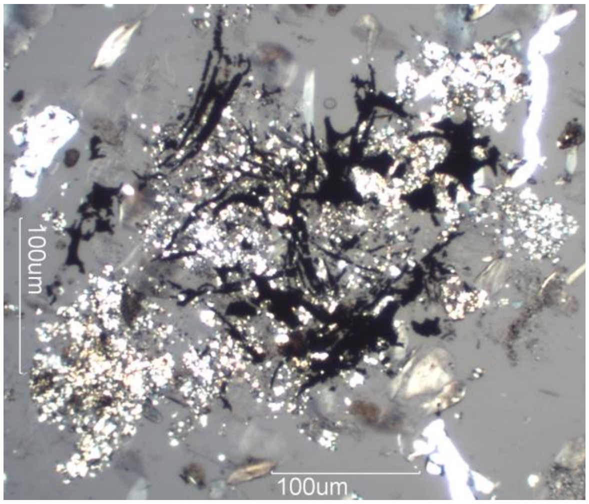
This field of view contains 4.3% black particles by image analysis. Skin flakes, trichome (plant hair), fragment of plastic, natural minerals, and cellulose are also present. The black particles include tire wear, charred wood from fireplaces, a paint sphere, magnetite inclusions, and toner fragments.

Soot, char, and ash (SC&A) analysis seems to have grown out of laboratories doing fungal spore identification and/or arson investigation. Wipe samples are a critical part of arson investigations but destroy much of the information needed to identify the source of the combustion particles. In an arson investigation the source of the combustion particles is known, it is the presence of accelerates that is in question. Wipe samples are not acceptable for wildfire smoke exposure investigations where it is the particles that must be identified.

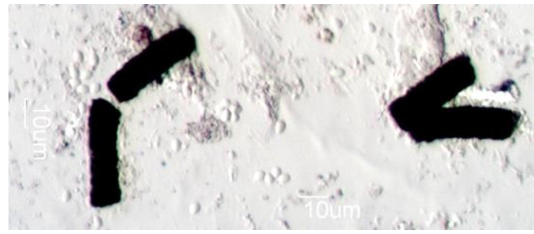
Fungal spore identification doesn't require the use of polarized light or reflected light examination. The use of clear tape is apparently adequate for that analysis. The limitations of applying this technique to the identification of wildfire emission will shortly become evident.

Identification of Smoke Debris

Indoor environments are impacted by a wide variety of combustion sources. Consider first the internal sources. Cooking is a pyrolysis of mixed fuels. The house dusts that settle on a stove top will be burned and become a pyrolysis product in the home when the unit, gas or electric, is turned on.



Photograph 3: Cigarette Ash, 20.4% Black



Photograph 4: Gnat Fecal Pellet (Frass)

This is frass from a mold eating Gnat on a tapelift from an attic.

Photograph 5: White Ash with Cell Structure

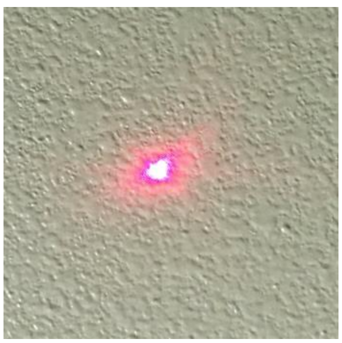
This type of fragile particle is destroyed when a wipe or vacuum sample is taken. This particle is white with reflected light.

Stoves are not the only source of combustion products in the home. Electric baseboard heaters have exposed coils that burn whatever has settled on them. The odor generated when the heat is first turned on is the result of baking these accumulated particles. In addition, incandescent bulbs get very hot and burn skin flakes, paper fibers, clothing fibers, etc., that then become airborne and settle on surfaces in the indoor space. Fireplaces (Photograph 2), cigarettes (Photograph 3), cigars, pipes, ovens, electrostatic filters, heat exchange surfaces in gas or oil furnaces, use of power saws or drills, candles or oil lamps, printers and copy machines, and other activities or products contribute to the combustion sources in the indoor environment, including toasters with or without burnt toast.

Outdoor ambient particles are a major contributor to indoor particle concentrations. Studies have shown the relationship between indoor and outdoor particle concentrations is influenced by the specific indoor/outdoor (I/O) ratio, ventilation, infiltration, and penetration factors[15]. These factors vary from one home to another. The largest single source of outdoor fine particles (PM2.5) entering homes in many American cities is the neighbors' fireplace or woodstove[16,17]. They also contribute significantly to the larger particles, ten micrometers and larger, in a home (see Photograph 2). Another mode for migration is soil adherence to footwear, clothing, pets, and anything else brought in from outdoors. These particles are brought into the home, released, and distributed throughout the space.

Combustion products are not the only black particles in an environment. Tire wear, shoe wear, fretting metal wear, dark minerals, insect debris, fungal debris, decayed plant material, insect and arachnid frass (see Photograph 4), newspaper ink, toner, cosmetics, pencil debris, etc. are always or often black and are not uncommon in indoor environments. The products of combustion are not all black or even dark. When all of the carbon is consumed the result is generally a white, yellow, or red ash. These particles still retain structure and optical characteristics sufficient to be identified as ash if they are carefully lifted from a surface (see Photographs 5 and 6).

The identification of these materials requires a mount of high optical quality. That is not possible with a tapelift unless the plastic backing is removed. The plastic backing is too stiff to conform to particles thicker than about three quarters of the adhesive film thickness. The adhesive film is typically ten to twenty micrometers thick (0.01 to 0.02 millimeters). As a result, particles thicker than about seven micrometers (0.007 millimeters) are often associated with pockets of air that mask their morphology and their optical properties. If the plastic film is removed without significantly disrupting the particles in the adhesive layer then the adhesive will conform to the particles and no optical gaps will be present. With the clear tapes used for SC&A analysis the plastic backing cannot be removed without serious disruption of the particles in the adhesive layer. A tape commonly used when a detailed analysis of surface dust is required is 3M Scotch Brand frosted Magic Tape. This tape has an acrylic adhesive layer for high adhesion and a cellulose ester plastic film that can easily be removed using acetone. High adhesion is required for efficient particle collection. Acetone has little effect on most environmental particles. The refractive index of the acrylic adhesive is about 1.48. With a mounting medium of about 1.49 the adhesive nearly disappears. The result when a glass coverslip is added is a high quality optical mount.

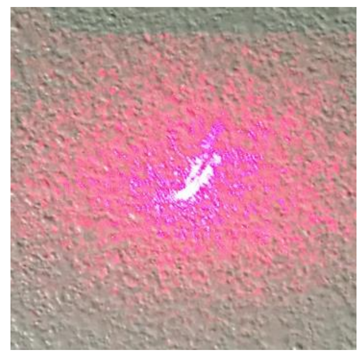


Photograph 7: The Point Pattern without a Slide in the Path

The diameter of the spot is about 3 millimeters with some scatter due to the pointer optics.

Photograph 8: Laser Speckle Pattern of Processed "Magic Tape"

The sharp image of the beam shows very little scatter, even when particles are present. The refractive indices of the glass, resin, and the adhesive are very close, which minimizes aberration of the particle image.



Photograph 9: Laser Speckle Pattern of a Typical SC&A analysis Tape

The flare and lack of definition in the beam diameter illustrates the poor optical quality of the plastic and the interfaces between the plastic, adhesive, and glass slide.

Photographs 7, 8, and 9 show the laser speckle pattern of a laser pointer with no slide present, with a processed environmental tapelift using frosted Magic Tape, and with an environmental tapelift using a common tape provided by laboratories using the SC&A analysis technique. The white spot in the center of these images is the result of overexposure.

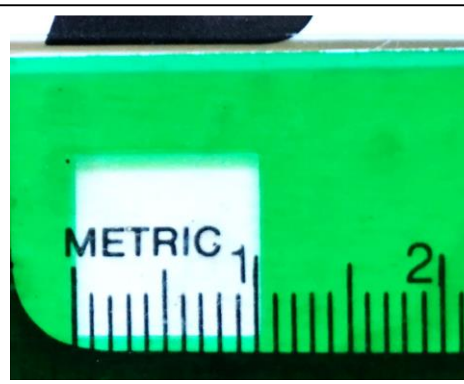
The laser speckle pattern of the SC&A analysis tape loses all coherence and the speckle pattern expands by a factor of 10 if particles associated with bubbles or gaps around the particles are included in the field. Photograph 8 represents a very clean area of the tape.

Photograph 10 shows a ruler under the slide that generated the speckle pattern shown in Photograph 7. This is the full area under the coverslip. The coverslip is a 20X40 millimeter, #0 coverslip. The entire 800 square millimeters are available for analysis as needed.

Photograph 10: A Processed Magic Tape Tapelift

This is a photograph taken through a processed Magic Tape tapelift of a plastic metric ruler. The area available for analysis is shown here. It is 4 centimeters by 2 centimeters approximately.

Photograph 11 shows a tapelift typically used for SC&A analysis on the same ruler. The tape is colored except for a small 10X10 millimeter window. The photograph was taken at the same scale as Photograph 10. The analyst is restricted to inspecting the 100 square millimeter area. A clean area of this sample with no air bubbles or gaps was used to generate the speckle pattern shown in Photograph 8. The plastic film is a polyethylene. The optical characteristics of polyethylene are inferior to glass, which results in reduced image quality. The tapelifts shown in Photograph 10 and 11 were taken from clean surfaces.



Photograph 11: Typical Tapelift for SC&A analysis

This is a photograph taken of the same ruler through a tape provided by a typical laboratory doing SC&A analysis. The analyst is limited to examining an area within the 1 centimeter by 1 centimeter window.

It is critical to remove air gaps and bubbles around particles. A gap between a particle and the mounting medium or the mounting medium and the glass slide adds a number of optical effects that mask the optical properties of the particle. These interfaces cause more light scatter, change the polarization of the beam of light, and can even completely overwhelm detail of the particle of interest.

Image aberration due to light scatter is not the only problem with the plastic film. The plastic is also optically active, meaning that it has different refractive indices in different directions. That prevents the proper characterization of particles in a number of ways. A critical part of the analysis of a particle under the microscope is determining how it affects a beam of polarized light. When the particle is fixed in a plastic film that is optically active subtle but critical effects can't be detected or measured. This defect is also present when plastic slides are used. That includes the depolarization at the interface of a conductive particle and the mounting medium, rotation of the polarization caused by internal reflection, rotation caused by molecular asymmetry, anomalous interference effects, polarization on reflection, and other effects.

One final comment on the tape shown in Photograph 10. The area available for analysis is inadequate. A critical member of an important assemblage may only be present at parts per thousands. Looking at less than a few thousand particles in an environmental analysis is generally not sufficient to characterize exposures. This often requires much more than one square centimeter of a tapelift.

Photograph 12: Forest After a Wildfire (Las Conchas)

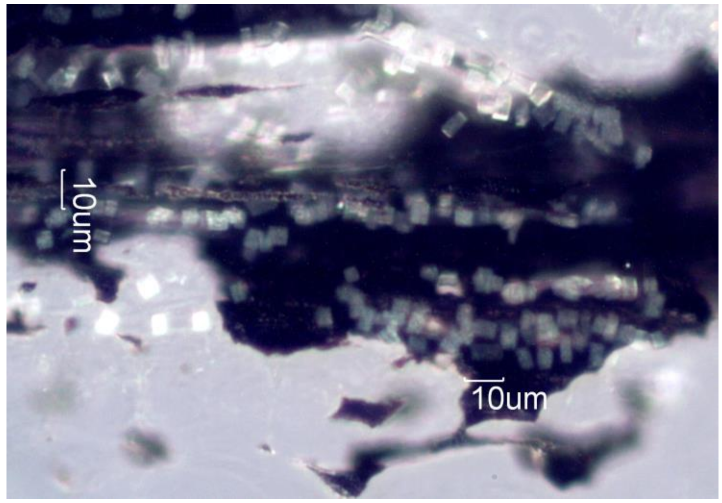
Most of the wood is still present but the leaves, needles, small twigs and some of the bark have been burned and were carried away as smoke particles.

Wildfire "Assemblage Analysis"

Wildfire assemblage analysis is based on the differences between wildfires, slash burns, fireplace fires, backyard plant waste fires, vehicle emissions, and about forty other sources of combustion products. Wildfires are unique and each biome has its own characteristics. The aftermath of a forest fire is shown in Photograph 12. Most of the wood is still present. The leaves, twigs, and much of the bark is missing. Some of the trunk is burned but much of the trees' wood remains. Wood is one of the minor fuels in a typical forest fire.

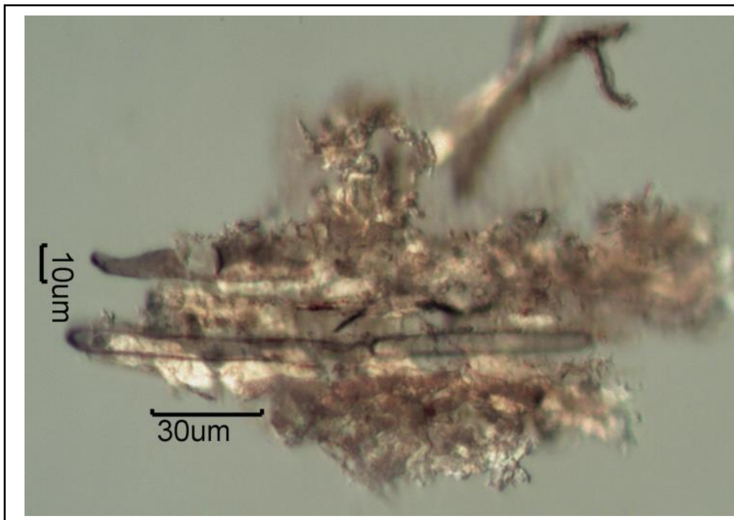
Trees are not the only fuel in a forest fire. Shrubs, herbs, and grasses also burn, along with the duff, degraded biological debris that has accumulated on the forest floor. Each of these fuels have distinctive markers as charred fragments and phytoliths, both silica and calcium oxalate (Photographs 13 and 14). The amount of these other fuels that burn will vary depending on their availability in a particular forest environment and the nature of the forest fire. A crown fire may miss most of the ground fuels, at least initially.

Much of the combustion debris from wildfires isn't black. Much of the ash is white (see Photograph 14). The silica and calcium oxalate phytoliths are generally not dark though the silica phytoliths are sometimes coated with soot. The calcium oxalate phytoliths are



Photograph 13: Douglas Fir Needle Char

This shows the pseudo-cubical calcium oxalate phytoliths of Douglas fir and the cell structure of the charred needle.



Photograph 14: Pine Needle Ash

This shows part of the needle cell structure, the silica phytoliths (colorless, transparent elongated plates), and the bipyramidal pyrolyzed calcium oxalate phytoliths. The orange color is due to light scatter. With reflected light this particle looks white.

generally white though they may be associated with charred plant material, as in Photograph 12.

What is burned in a fireplace? The purpose of the fireplace is to maximize the burning of the wood. Leaves and twigs are not typically burned in the fireplace and the amount of bark burned is minor compared to the amount of wood. Charred wood is a major combustion product of fireplaces and woodstoves.

Burning of yard waste, agricultural field burning, and the burning of orchard pruning are all distinctive sources. Even slash fires or back fires are often distinctive because their purpose is to remove the "ladder fuels" and tinder from the forest floor. Shrubs, herbs, and grasses are the main fuel, along with deadfall and duff. The products of these intentional fires are not the same as the uncontrolled burn of a wildfire.

Forest wildfire smokes are relatively easy to identify due to the characteristic pyrolysis products of the calcium oxalate phytoliths that are concentrated in the needles, leaves, and bark of trees. Chaparral wildfires leave a different mark (see Photograph 15). After a chaparral wildfire the charred trunk and larger branches of the vegetation are still present. Just as in the forest wildfire it has been the leaves, twigs, dry flower heads, and bark that are the main fuel. Chaparral is a mix of plants just as is the forest but the mix is different. Adenostoma species, Oak, Brittlebush, Agave, Sumac, etc. are common in Southern California. At higher elevations and in other States Mountain Mahogany, Feltbush, and Sycamore may be added as other species become less common. Every biome is different, just as in the case of forest fires.

Photograph 15: Leaf and Twig Char, Adenostoma

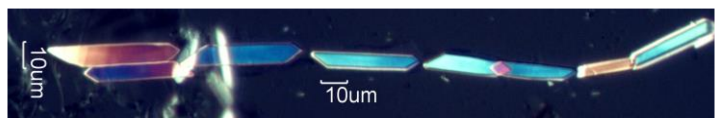
Adenostoma charred resin droplets are on the left and charred vessel cells from the stock of the plant are on the right. Diamond shaped calcium oxalate phytoliths are also typical of Adenostoma (not shown). Two Adenostoma species dominate much of the Southern California Chaparral. One is known as Red Shanks, Adenostoma sparsifolium, and the other is Chamise, Adenostoma fasciculatum.

Savannah or grassland fires also have a distinctive assemblage (see Photograph 16). The silica phytoliths of the grasses and the charred fragments of leaves are easily identified and are not like any other common non-wildfire source. Sagebrush, Brittlebush, Rabbit bush, and dozens of other low shrubs and herbs add to the assemblage depending on the location of the savannah. Grasslands in Southern California are not the same as the grasslands of Eastern Washington State. Each location has its own characteristic assemblage. That is why knowing the location of the fire is important to the analysis.

Photograph 16: Charred Brittlebush Following a Grassland Wildfire

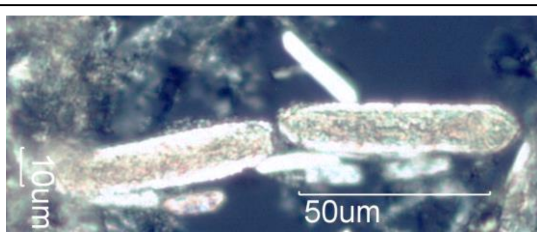
This was from a wildfire near Banning, California. Notice that the grasses and smaller herbs have been burned to the ground level but shrubs and small trees

The calcium oxalate phytoliths are thermally sensitive and change their optical properties as seen using polarized light even though their shape stays typical of that plant type and that part of the plant (see Photographs 17 and 18). The silica phytoliths retain their shape but are often coated with a layer of coked plant material or soot (see Photograph 19).



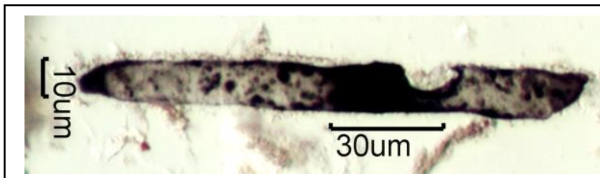
Photograph 17: Pine Calcium Oxalate Phytoliths

Calcium oxalate phytoliths from pine have this characteristic elongated bipyramidal shape.



Photograph 18: Burnt Pine Calcium Oxalate Phytoliths

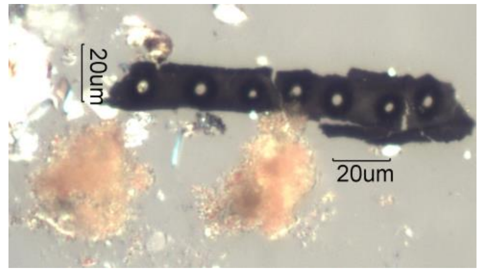
Calcium Oxalate passes through a number of chemical reaction as it is exposed to heat. It may then go through some additional chemical reactions in the plume, but the shape is still recognizable.



Photograph 19: Charred Silica Phytolith

Pine needles also have characteristic silica phytoliths. These can be a common particle in pine forest soils but when coated with soot, as in this case, are the product of combustion.

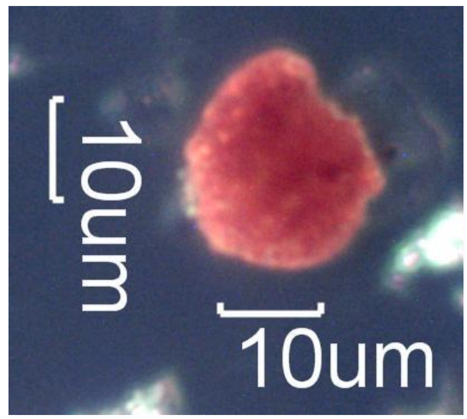
A characteristic of wildfires is that they create their own weather. The powerful convective air currents carry particles of soil with them. As these particles are carried through the combustion zone the iron they contain is oxidized. Most soils contain biogenic or leached iron that changes the clay and other soils brick-red when they are oxidized (see Photograph 20). This burnt clay becomes another part of the wild fire assemblage.



Photograph 20: Burnt Clay

A fragment of charred Ponderosa pine is above the two Burnt Clay particles.

Air dropped fire retardant is often used to help control wildfires. These fire retardants are a mixture of phosphate and sulfate salts with iron oxide as a pigment. The pigment is added so that past applications can be seen from the air. That helps guide the next application so that the same area is not covered twice. Photographs taken of an aircraft making these drops show the main body of the material dropping vertically and a pink trail of very fine aerosolized fire retardant. These fine red aerosols become part of the plume from the fire and can often be found in tapelifts from homes exposed to the smoke from the wildfire (see Photograph 21).



Photograph 21: Fire Retardant Aerosol

This particle is from a tapelift collected in a home exposed to smoke from a wildfire.

This collection or assemblage of particles becomes the unmistakable signature of a wildfire[2,14]. Fire retardant may be absent on occasion. In some environments the natural red clay can complicate the analysis. In these cases it becomes more important to identify more of the plant types as part of the assemblage to increase the confidence in the conclusion of exposure to wildfire or the lack of that exposure.

<u>Wildfire "SC&A analysis"</u>

Wildfire SC&A analysis is described by most laboratories as the identification of the presence of charred biomass, soot, and ash. The biomass is not characterized as to the type other than it is assumed to be plant, based on visible cell structure. The microscopists in many of these laboratories are highly trained and very good at what they do but there are a number of interferences in any sample that can complicate the identification of a particle as a plant pyrolysis product. These laboratories typically use clear tape applied directly to a microscope slide. Clear tape presents a number of problems for an analysis of opaque or dark particles. It is not as clear as optical resins typically used for microscopical analysis. ASTM D7910 requires only "reasonable optical quality". Figure 1 and 2 illustrate some of the differences between a clear tape mount and a prepared frosted tape mount. Figure 1 shows the optical interfaces in a clear tape mount. The first interface is between air and the top layer of the tape. The second layer is between the plastic film and the adhesive. These two materials are reasonably close in refractive index and so don't introduce much scatter. The third layer is between the adhesive and trapped air. The particle is not in a bubble but with a complex shape the particle is not uniformly wetted by the adhesive. The result are gaps that distort the image of the particle and create light scatter. The presence of these gaps creates another interface, four, between the gap and the particle. The fifth and sixth interfaces are the result of the gap between the particle and the glass slide. A simple example of this effect can be seen by applying a piece of frosted or clear tape to a glass slide, turning the slide over and looking at the reflection from the tape-slide interface. The tape will appear darker where it has wetted the surface of the slide. In the other areas the additional interfaces result in reflected light and areas that are brighter. For particles with simple shape that are smaller than about five micrometers in thickness the air gaps may not be present but for many particles the presence of these gaps is a major limitation in image quality.

Figure 2 shows the optical interfaces in a mount made with frosted 3M Scotch Brand Magic Tape. The first interface is the same with the exception that the top layer is an optical glass coverslip and not plastic. The interface between the coverslip and the optical resin is a near refractive index match as is the interface between the optical resin and the adhesive. There is no gap between the particle and the adhesive because the acetone soak allows the adhesive to completely wet the particle. That removes the presence of any air gap. The result of these cleaner interfaces shows in the laser light scatter shown in Photographs 8 and 9.

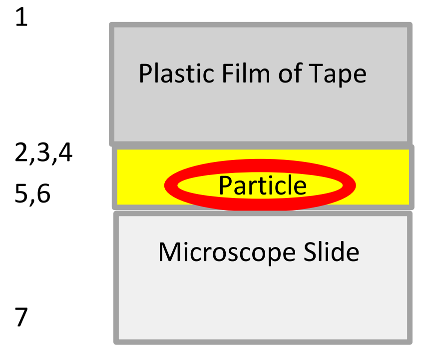


Figure 1: Clear Tape Interfaces

Light is scattered by the intrinsic optical quality of the material it passes through and at every interface with a significant difference in refractive index across the boundary. There are typically seven interfaces through a clear tape mount: 1 air to Plastic film, 2 plastic film to adhesive, 3 adhesive to air gap, 4 air gap to particle, 5 particle to air gap, 6 air gap to slide, and 7 slide to air.

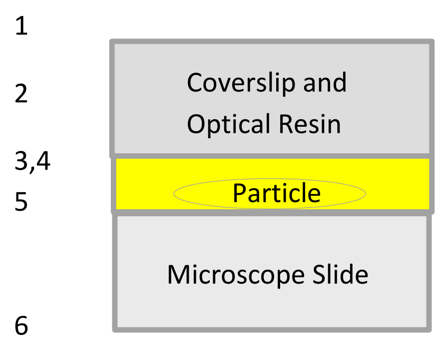


Figure 2: Prepare Frosted Tape Mount

The interfaces: 1 air to glass and, 2 matching optical resin, 3 optical resin to near match adhesive, 4 adhesive to wetted particle, 5 particle to slide, 6 slide to air.

When reflected darkfield illumination is used there is more light scatter with clear tape than with optical resin and a glass coverslip because the light must travel twice through interfaces 1, 2, 3, and 4. Interfaces 3 and 4, the air gaps between the adhesive and the particle, are the major problem. Each pass creates more light scatter. Light scatter is like looking though fog. The fine features that distinguish charred bark from tire wear become impossible to see. The mount is further compromised by not being flat. The proper identification of dark particles becomes very difficult. Tire debris, dark minerals, cenospheres, magnetite spheres, and many other interfering particles can be misidentified as char, false positives. Char can be misidentified as tire wear or rotted biologicals rather than charred biologicals, false negatives.

The definition of ash creates more uncertainty in the analysis. One reputable laboratory defines "Ash" as "a high carbon containing particulate that does not maintain its original form". In other words, a black particle that has no definitive shape. That would be very hard to distinguish from tire wear or any number of other black particles that are not the result of combustion. That has led to problems in some cases (see Case Histories below). That definition of ash also excludes white ash that may be a considerable part of the total wildfire emissions at a given location (see Photographs 4, 5, and 13).

The definitions of "Soot" and "Char" are no more well defined than "Ash" which results in the inclusion of many more possible interferences. Many sources produce charred plant biomass that are not wildfire related. Charred wood from fireplaces is much more easily identified than charred bark or fine ash from leaves or other plant parts. Field burning, slash burning, and other non-wildfire combustion sources produce much more of the type of material identified by this approach. The burning of candles is identified in these reports as a possible interference for soot identified as being from wildfire. Basically, the reports indicate that the source of the particulate matter should not be assumed based on this analysis and that they are not responsible for how this information is interpreted. Further, the results are unreliable in that any change in the method could produce very different results of at least equal validity. That leads to the common and appropriate precaution added to most of these reports shown below. It should also be added that there are no "published standard methods" for wildfire analysis although their disclaimer suggests that some exist and they comply[18]. That is a misstatement.

A Common Precaution Attached to "SC&A analysis" Results

The results are obtained using the methods and sampling procedures as described in the report or as stated in the published standard methods, and are only guaranteed to the accuracy and precision consistent with the used methods and sampling procedures. Any change in methods and sampling procedure may generate substantially different results. The laboratory assumes no responsibly or liability for the manner in which the results are used or interpreted.

The limitations of this approach are not necessarily due to the lack of skill on the part of the analyst but are limitations imposed by the way the analyst is required to perform the analysis.

Quantification of Smoke Debris

The purpose of quantification after a wildfire is to assess the extent of exposure to the emissions from the fire. In order to determine the amount of combustion material present it must be quantified based on its amount per unit area and not on the amount of other particulate matter present. The amount of other debris in that space relates to the general cleanliness of the surface and has no significance relative to the impact of smoke from the wildfire. The error of quantification based on a percent of the total particle population is pointed out in another disclaimer often present on SC&A analysis reports. It points out that the percentage of SC&A will decrease with time due to the accumulation of other dusts even if no remediation has been done. The approach of "Assemblage Analysis" and "SC&A analysis" is very different in this regard. Only the "assemblage analysis" method is independent of the background particle loading and other combustion sources.

Another complexity associated with Wildfire SC&A analysis compared to Particle Assemblage Analysis, investigators need benchmarks or thresholds to which they compare their results. There may be no published data against which field data may be compared. Comparison data may be based on in-house research or other published information. However, in many cases internal research and published information may not be appropriate, as this data may not account for regional variations, site-specific characteristics, variations in collection media or the presence of alternative combustion sources. Scant agreement among hygienists and their organizations on a concentration level that would constitute "damage" and remedial action only further complicates the task[18].

Particle Assemblage Analysis suffers from a related problem. Correlating "damage" to the level of wildfire debris is not part of the analysis. The advantage of assemblage analysis is that it represents the actual exposure to debris from the wildfire and not simply combustion products or black particles as a percent of other particles at the site.

"Assemblage Analysis" Quantification

"Assemblage Analysis" Quantification is based on the area of a tapelift that must be examined in order to see the required wildfire assemblage. It has the advantage of being independent of the particles that are not related to wildfire. Whether the surface was clean or dirty prior to exposure doesn't matter. The presence of a fireplace or woodstove won't interfere with the results because such sources don't contain the wildfire assemblage and the addition of charred wood doesn't decrease or increase the area that needs to be scanned in order to find the wildfire assemblage. The time since exposure with the accumulation of other particles is irrelevant. The sole criterion is how much of the surface is covered with particles from the wildfire.

The area examined is based on the number of scans across the tapelift required to identify the wildfire assemblage or to establish that it is not present at a significant level. In some cases, the exposure is so great that nearly every field of view, about 1/25th of a single scan, contains the entire assemblage. In this case the exposure is reported as “high”. If a full scan is required, then the exposure is reported as “moderate”. If a few scans are required, then it is reported as “low”. If many scans, up to ten or a few more, are required then “trace” is reported. For samples at the trace level other combustion sources often exceed the amount from wildfire but wildfire debris is still present. If the assemblage is still not complete after twelve scans, then “non-wildfire” is reported. That doesn’t mean that there was no exposure but that the exposure at this surface was so low as to be inconsequential or has already been remediated. The home may be recontaminated if the environment at large has not been remediated. That includes the exterior environment that is remediated naturally by weathering conditions. Weathering occurs when exterior temperatures cycle above and below the dew point, by precipitation, and by aging of the combustion products that tend to fix them in place.

“SC&A analysis” Quantification

Laboratories using “SC&A analysis” use one of three referenced methods. The most common method is “Visual Estimate”. Visual estimate involves looking as the sample and estimating the relative amount of area covered by SC&A compared to the area covered by other types of particles. This is a notoriously inaccurate method when percentages are under ten percent, even when the material being quantified is well defined and being done by “experts”[19,20]. Differences of at least a factor of two are not uncommon between experts at a level of ten percent and the difference increases as the percentage decreases. Size also affects estimation. The reader is encouraged to look at Photograph 1 and 2. The amount of black material in those images was measured using an image analysis program. Does the amount of black materials in Photograph 2 look like five times as much as the black material in Photograph 1? The human eye is not good at estimating percent coverage in a field of view.

A second method of quantification used by some laboratories using “SC&A analysis” is to count particles and generate a percentage based on count. Although it might sound more scientific than a visual estimate in reality it is not. If all of the particles were the same shape and the same size it would be fine, but they are not. The analysis may be improved a little by only counting particles larger than a certain size, say three micrometers or larger. If the particles were all spheres that would help but do we mean three micrometers in length, in width, in equivalent spherical diameter, an average of six ferrets, or some other measure? Is there an upper limit restriction? Is one three micrometer particle the equivalent of a thirty micrometer particle? Visually estimated area coverage is beginning to sound better.

A third approach attempting to compensate for the defects in the second method is to use a random point array as the basis for counting. That sounds better but it also suffers from problems related to sample size, especially for materials at low percentage coverage or for particles of small size widely distributed [21].

The problem with all of these methods is that they compare the materials called wildfire debris to the total particle loading in the sample. If a surface was dirty before exposure to the wildfire, then the wildfire contribution may be small even with a significant exposure. Similarly, if the surface was clean prior to exposure but the sample wasn't collected until ten months later, a common situation, then the contribution of wildfire debris is a lower percent than if the sample had been collected shortly after the fire, a few months after the fire or even five months after the fire. This approach is not a measure of the exposure to wildfire debris. It's a measure of how clean the environment is relative to the debris from wildfire. That is assuming that the debris from wildfire has been accurately identified to begin with.

There are better ways of estimating the quantity of wildfire related particles in a sample but they are also more expensive and are still subject to the accuracy with which the particles are identified. They are also limited by the accuracy of the estimation of the third dimension of the particle. The third dimension, thickness, will vary depending on the type of particle and even the specific particle involved. A flake of mica will be different than a rhomb of a carbonate mineral. A skin flake will be different than a hair or feather barbule. A rat hair will be different than a dog or cat hair because their cross-section is different to say nothing or their relative density. A number percent may seem more accurate but in reality it is still a guess no matter how it is generated and has little to do with the actual exposure per unit area in the home.

CASE STUDIES

The best way to see how these differences in approach, assemblage analysis or SC&A analysis, is to compare results with real world examples. All of the laboratories involved in the following case studies claim to be the experts in the identification of wildfire smoke exposure. They all claim to be able to defend or have successfully defended their results in a court of law. They will not be identified by name but all are generally considered to be reputable laboratories. The purpose of these studies is not to challenge the ability of the analysts but rather the analytical method used and how the results of the analyses were interpreted.

Case Study 1: Roadside Smoke Debris

A study of sixty-four (64) homes was conducted to assess the impact of the Las Conchas wildfire to homes in New Mexico[22]. Each home was sampled using alcohol moistened one inch by one inch pads. The samples were collected over the late Fall and Winter of 2011-2012, four to nine months post-fire. The surfaces sampled included windowsills, tops of fan blades, tops of shelves, and tops of door jams. The area sampled was not recorded. The wiper was applied to the surface until discoloration was observed. That may have been one wipe or multiple wipes. These samples were then sent to a laboratory using the "SC&A analysis" procedure described above. But before this procedure could be applied the particles had to be removed from the wiper and applied to a microscope slide. How the particles were extracted and how they were mounted on the slide was not provided.

Fifty of the sixty-four homes were reported as being impacted at some level. The homes that showed the least impact were the ones furthest from any major road. Most of the homes that showed a significant impact were on a major highway or within a few hundred feet of a major highway. This pattern of proximity to a major roadway and what was interpreted as exposure to the Las Conchas fire was a dominant feature in these results. Distance from the fire had no effect. Along the same trajectory proximity to a major road was the only correlation to what was interpreted as exposure to wildfire. Tire wear and vehicle emissions would appear to be what was being interpreted as SC&A from the wildfire.

Twenty-six homes in this same area were sampled a few months later using Magic Frosted tape tapelifts and "Assemblage Analysis". None of these homes had been examined in the first study. The Las Conchas fire was a forest fire burning Ponderosa pine, some Spruce, shrubs, herbs, and grasses. This was a large fire and the plume was still evident hundreds of miles away in Texas. The assemblage associated with this fire included pyrolyzed pine and spruce calcium oxalate phytoliths, needle ash, bark char, wood char from pine, spruce, and hardwood char from shrubs, carbon coated silica phytoliths from grasses and needles, deciduous leaf ash and char, burnt clay, and fire retardant aerosol particles. In some instances, residue from the fire was detected in homes sampled as much as eighteen months after the fire was controlled.

Of the two hundred thirty-two (232) individual tapelifts analyzed one hundred sixty (160) showed no wildfire. That was sixty-nine percent of the samples. All of these non-wildfire tapelifts had tire wear, charred wood, insect debris and other black particles on them. Seven of the twenty-six homes showed no wild fire emissions on any of the tapelifts collected in the home. These homes included homes sampled eleven to eighteen months after the fire. Of the remaining nineteen homes only two showed any tapelifts with levels above trace exposure. Only one of ten in one home and three of ten tapelifts in the other showed values above a trace level. One of these homes was in Ojo Caliente and the other was in Truchas. These tapelifts were collected on surfaces that had never been cleaned since the fire. The tapelifts were from the top of a light fixture in a bathroom, the top of freezers in the garage, and the top of a beam in the living room. Both of these homes were near major roadways but many of the homes that showed no presence or only trace exposure to the wildfire were on or within a few hundred feet of major roadways.

Finding the assemblage of particles that indicated the Las Conchas wildfire on a few scans across the tapelifts certainly provides more confidence in the results than the detection of black particles. The fact that the high SC&A analysis results correlated so well with proximity to major roadways strongly suggests that it was tire wear and vehicle emissions that were being interpreted as debris from the Las Conchas wildfire.

Case Study 2: The 1% Rule

In the State of California, the presence of 1% SC&A has been accepted in litigation as proof of exposure to smoke from a wildfire. Black particles that fit the poorly defined description of SC&A exceed 1% in most homes with no exposure to wildfire. This is based on studies done by laboratories that used their SC&A criteria. Another problem with the 1% rule is that it has no basis in any scientific study. Indoor environments often contain black particles far in excess of 1% regardless of how that 1% might be measured (see below). There are a large number of environmental combustion sources that are not wildfire. These sources often exceed 1% as reported in the literature. So 1% doesn't establish wildfire exposure. Is there some other percentage that would work? That introduces the next problem.

Reporting a percentage indicates that something has been measured as a baseline and a subset has been separated and measured to establish a relationship between the subset and the total. The question is subset of what and how is it measured? It is usually interpreted as 1% of the total particle load. Is that 1% by area, by weight, by count, or some other parameter. In some soot reports it is by count, in others it is by estimated total particle area or by estimated weight assuming some density for the particles in the sample, in still others it is by area sampled. Each of these would provide very different numbers. Count provides what appears to be scientifically reliable numbers but what do the numbers mean? One particle 25 micrometers in diameter should count more than a particle 3 micrometers in diameter. The percent based on count will be strongly biased toward the smaller particles and in the case of a wipe sample, where delicate char particles are crushed, would significantly overestimate the amount of soot and char present.

Wipe samples couldn't be used for estimated particle percent by area either. The collection efficiency for a wipe on a perfectly smooth surface is at best around 75% but that collection percentage varies by particle type and by particle size. For surfaces that are not perfectly smooth the collection efficiency drops rapidly. Wiping a given fixed area doesn't mean that that area was sampled with equal efficiency for different particle sizes and types or even that the collection efficiency for the same type and size of particle was the same over the area wiped. Wipe samples are quite unreliable as a particle collection technique if quantification is important.

Tapelifts with an adhesive pull strength greater than 30 pounds per square inch (acrylic adhesive) are about 98% efficient at collecting particles from surfaces whose particle area coverage is 20% or less and is still about 90% efficient with area coverage of 60% for relatively smooth surfaces. Tapelifts are the desired collection technique of soot char and ash because they are efficient and they retain particle configurations and associations that are important for the accurate identification of the particles. Percent of total particle area or of area sampled could be determined using tapelifts.

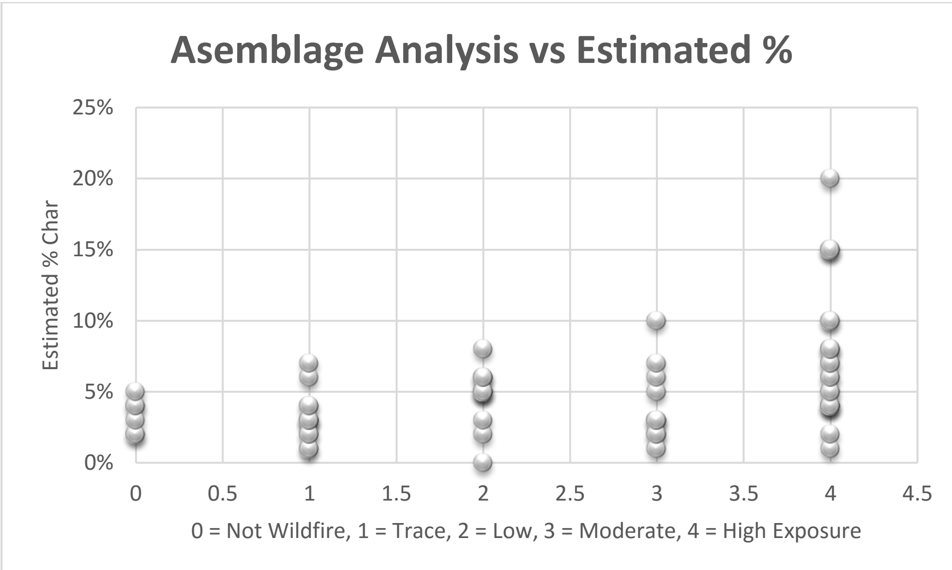
The next problem with the 1% rule is that it is often based not on any measurement but rather on estimation. Humans are poor at estimating percent coverage of anything. They are much better at comparing coverage. Some laboratories use a set of standard images representing different levels of coverage for this reason. It improves the reliability of the estimate in proportion to how closely the standard look to the sample being examined and the ability of the analyst to integrate estimates over a number of fields of view. It is still an estimate. Image analysis is not a significant improvement although it sounds better, because of the additional time required to determine if a given particle actually is from the fire in question. Image analyzers see the world in black and white. The greys still have to be interpreted by a human analyst, something humans are very good at with sufficient training. But the human judgement is still part of the analysis and the analyst must decide which particles to include. That is the next problem.

Particles in the smoke from wildfires are not all black.

The environment is full of black particles. Near heavily traveled roads tire wear alone can be as much as 10% of the total particle area on indoor surfaces. Emissions from fireplaces, woodstoves, and Fall and Winter slash burns can dominate the atmospheric particle burden in the Fall and Winter. Charred wood and soot and ash from combustion of wood in fireplaces and wood stoves have been estimated to account for 40% to 60% of the cool weather air pollution in temperate climates. That is exactly when most wildfire investigations are conducted. Charred wood is a very common environmental contaminant in homes without exposure to wildfire. Because of this background charred wood is not an indicator of wildfire exposure by itself. Charred wood can exceed 1% in a home even without wildfire. Homes with fireplaces or woodstoves often exceed 1% charred wood as a result of blow-back from wind conditions or inadequate draft. Even homes without fireplaces or woodstoves can contain more than 1% charred wood due to the fireplaces and woodstoves of neighbors. The 1% criteria has no scientific validity.

Case Study 3: Duplicate Analyses, "Soot" vs. Assemblage Analysis

A number of homes with suspected smoke damage from wildfire emissions were sampled with side by side tapelifts. One set was sent out for "standard SC&A analysis" and the other set was sent out for assemblage analysis. There were a total of sixty-one paired samples. In each case the SC&A analysis was performed on clear tape looking at a subset of a 1 centimeter by 1 centimeter area. The assemblage analysis was performed on a tapelift using a cellulose ester frosted tape (Scotch Brand Magic Tape). After the tape was placed on a microscope slide the plastic cellulose ester layer removed with acetone. The adhesive with the particles was then covered with a synthetic resin that was a near match for the refractive index of the adhesive and the added coverslip. The area examined for assemblage analysis ranged from 0.4 square centimeters to 8 square centimeters, depending on the area required to find the members of the wildfire assemblage or determine that it was absent. The chart below shows how the results compared. The assemblage analysis results were converted to numerical values by assigning "Non-Wildfire" to "0", "Trace" to "1", "Low" to "2", "Moderate" to "3", and "High" to "4". The assemblage analysis results are shown along the X-axis and the matching SC&A analysis results are indicated by the Y-axis. All 61 of the matched tapelifts are represented on the chart. Many of the points represent more than one pair of analyses.



The chart demonstrates that when assemblage analysis detects a high level of exposure to wildfire smoke the probability of the SC&A analysis also finding a high level increases. It also indicates that a SC&A analysis value of under 5% can occur at any level of exposure determined by assemblage analysis, non-wildfire (0) to high exposure (4). Similarly, a value of 5% or more can occur at any level determined by assemblage analysis.

There were six tapelifts determined to be high wildfire exposure by assemblage analysis that were reported by SC&A analysis to be under 5% SC&A. Four of these six were from one home exposed to the Las Pulgas fire. The Las Pulgas fire was finally controlled in May of 2014. The samples from this home were collected in February of 2015, ten months after the fire was controlled. All of them were windowsill samples and the total particle loading determined by obscuration on the tapelifts was in excess of 20% of the total area on some parts of each of the four tapelifts. The combustion debris on these tapelifts was dominated by white ash and calcium oxalate phytoliths that had been exposed to high temperatures. The black particles present included tire wear, fungal debris, charred wood, charred bark, charred leaves, charred resin, and insect frass and fragments. The charred plant debris include herbaceous plants, some shrubs, and desert plants. Most of the white ash was from the herbaceous plants and shrubs. The relatively heavy loading of particles and the moderate loading of black particles was consistent with the SC&A analysis values reported for other tapelifts with a similar ratio of black particles to total particle loading. The higher than normal level of white ash from this fire at this location contributed to the low estimate in two ways. First, white ash didn't comply with any of the combustion particle definitions used by the SC&A analysis. It was excluded from the wildfire particle estimate. Second, since it wasn't included with the wildfire particulate matter it added to the particle population of things other than SC&A. The presence of white ash actually reduces the estimate of combustion related particles using the soot, char and ash protocol.

In another home well away from the home above but also reportedly exposed to the Las Pulgas fire the SC&A analysis results were about the same as was found in the home cited above but assemblage analysis indicated far less exposure. These tapelifts had also been collected about ten months after the fire was controlled. The total amount of black particulate matter was about the same or a little less than in the case above, but most of the black particles were tire wear. The tire wear particles were apparently influencing the quantification. The assemblage analysis results for this home ranged from non-wildfire to low exposure for these matching tapelifts. The amount of ash and pyrolyzed phytoliths was very much lower or absent on this set of tapelifts.

The SC&A analysis results and the assemblage analysis results were in good agreement at a home exposed to the Etiwanda fire. The Etiwanda fire was controlled in May of 2014 and the tapelifts were collected in January of 2015, eight months after the Etiwanda fire was controlled. Much of the material from the wildfire in this home was charred plant material along with the rest of the fire assemblage.

A home reportedly exposed to the Colby fire was found by assemblage analysis to have at most a trace exposure while SC&A analysis reported high values for SC&A exposure. These samples had been collected four months after the Colby fire had been controlled. The surfaces with the highest exposure according to the SC&A analysis were taken from a shelf in the garage and the headboard of a bed in a second floor bedroom. The black particles in the garage were dominated by tire wear, tailpipe emissions, high hydrocarbon content soot, wear metal, magnetite spheres, and charred plant material. The black material on the headboard included charred wood, charred cotton, charred skin flakes and charred plant material. Assemblage analysis identified that there was some ash and rare pyrolyzed phytoliths on these tapelifts. In preparation of this paper the notes from the home inspector were revisited. This home had two fireplaces in the home, they burned incense, and there were two barbeques and a fire pit outside very near the exterior of the home. That was consistent with the assemblage analysis results that detected combustions sources that were not from the Colby fire. The SC&A results responded to these combustion sources, like the incense, but also to the elevated tire wear in the garage.

The limitations imposed by the use of clear tape significantly limited the analytical capability of the SC&A analysis. That analysis was further restricted by the limited area available for inspection. The SC&A analysis concentrated on black particles and completely missed cases in which white ash was a significant part of the combustion particle assemblage. It also tended to indiscriminately ascribe black particles to wildfire even when wildfire debris was absent. As a result, SC&A analysis over estimated exposures to wildfire smoke in some cases and under estimated exposures in other cases, based on paired tapelifts.

DISCUSSION

Assemblage analysis actually looks for the markers that indicate what is burning. Every fire has different markers and the markers may change as the fire progresses, but they are still the same plants. What was char from a plant may become white ash as the conditions change. The part of the plume to which a home is exposed may affect how the assemblage presents itself. In one investigation the home was clearly exposed to a fire consuming plants similar to those in the wildfire plume but the concentration of tree related particles was inconsistent with the plume from the wildfire. A check of activities in the area of the home discovered a backfire had been set in an area that had been logged a few years before. Many of the understory plants had grown back but the trees were largely absent. The backfire was to protect this neighborhood. This home had been impacted by the backfire, not the main wildfire.

Investigating the exposure of a home to wildfire smoke requires some basic familiarity with the materials being burned and how these materials burn. Photographs 12 and 16 are an example. Wildfires are very selective in what they burn. Some basic familiarity with the plants in the area of the wildfire is required. That means the analyst must know the name of the fire involved. Then reference materials can be reviewed to characterized the biome[23,24,25,26]. Knowing the major plants indicates the fuels and what markers should be present. An additional source of information on the plants that are burning is often available on the internet in area specific publications[27,28]. Searching for information on the fire provides photographs of the fire and the fuel. A review of plants in the area provides more detail on the fuel. Microscope slide libraries or photographs of debris from wildfires of different types provide the reference materials[29].

Applying assemblage analysis to environmental samples requires special training not typically available from a University curriculum. As in any specialized area of analysis, the analyst requires specialized training and experience under a mentor. It is not the laboratory that has the skill, it is the analyst. The analyst must recognize the thermally modified calcium oxalate phytoliths[30]. The analyst must recognize the cross-field pitting, the bag cell pores, the structure of conifer pores, the fine structure of hardwood tracheids, the leaf cell-island structure, grass silica phytoliths, etc.[31,32,33,34].

As was shown in Case 1 and Case 3, assemblage analysis was able to identify the debris from a specific wildfire and to determine its semi-quantitative concentration on surfaces in the home. SC&A analyses were basically black particle analyses. It is not for lack of potential skill but the methodology used and the definitions applied to the particles that severely limit the quality of the results. The materials generated by a wildfire range from black particles difficult to distinguish from tire wear or fireplaces emissions, to ghostly white ash that still retains some cell structure or pyrolyzed calcium oxalate phytoliths. A tapelift sample of high optical quality is required to identify these materials. Some of the materials that mark the wildfire are present at low concentrations. It may be necessary to examine many square centimeters of a tape lift to find the assemblage require to have confidence in the level of exposure or lack thereof.

The clear tape used for SC&A analysis lacks the require optical quality and introduces optical artifacts due to poor wetting of the particle surface. As a result, the analysis is largely limited to identifying black particles with slightly more discernment than determining that the particle is black or at least opaque. There is no provision under the definitions used to identify white ash or the white calcium oxalate phytoliths characteristic of various plants involved in the fire.

Charred wood is always present to some extent in indoor environments. It comes from fireplaces, fire pits, wood stoves, distant wildfires, hog-fuel boilers, agricultural burns, construction activities, yard waste burns, etc. Finding charred wood in a sample without the other materials characteristic of a specific fire has little significance in regard to exposure to that fire. It is not surprising that there is little correlation between the results of a SC&A analysis and an assemblage analysis of the same surface in a home.

A SC&A analysis doesn't require any information about the fire that is supposed to be the source of the combustion products. Assemblage analysis requires that the analyst know the source. Looking for a pine forest fire exposure won't help if the smoke was from the house next door that burned down. The answer "no exposure to pine forest fire" is irrelevant to potential damage from house fire smoke.

In one case a set of samples was provided with a number of sample sets from a wild fire. The assumption was that this one set of samples was from the same wildfire as the other sets of samples. The analysis indicated a trace level of exposure to wildfire but the plant assemblage was different. The analyst added in the e-mail that went with the report that it looked like this home owner was burning trash, including plastic, in their fireplace. There was a significant amount of combustion products that were not from wildfire. The conclusion in the report was that there was a trace of wildfire exposure but it was not consistent with the wildfire in question.

The client was unhappy with the report because they wanted to know about exposure to a plumbing warehouse fire. The fire was so intense that it had burned the plants in a parking strip adjacent to the parking lot, including shrubs and trees. This parking strip was between the home in question and the warehouse fire. This new information explained all of the combustion products, including the plastic from all of the plastic pipe that had burned. It also explained the assemblage of plant combustion products that didn't match the wildfire of the other samples. The exposure to the warehouse fire smoke was now reported as "high". The probability that the home owner would have tolerated the odor of burning plastic in the fireplace was low. The amount of burned plastic and tar in the home was consistent with the debris that would come from this plumbing warehouse. The assemblage was there but it was not what the analyst was looking for. The point of this example is that to control the cost of the analysis the focus is on one assemblage. The combustion products that don't belong to that assemblage can be excluded and don't need to be characterized beyond the point where it is determined that they don't belong. A much more detailed analysis can be conducted but the cost of the analysis increases as does the time required for the analysis. Cost, inevitably, is a main driver in any analysis.

CONCLUSION

Assemblage analysis is the only approach that actually identifies the emissions from a specific wildfire as being present in an indoor environment. The initial expectation was that there would be a high number of false positives using the SC&A criteria. Instead, there were as many false negatives as there were false positives. Assemblage analysis tended to detect the presence of emissions from a wildfire in homes when SC&A analysis missed its presence. White ash and pyrolyzed calcium oxalate photoliths were generally the problem in these cases. Particles that are not black that come from a wildfire are not recognized in the definitions used for soot, char and ash analysis. SC&A analysis has never claimed to identify emissions from a specific wildfire or even to determine if the combustion products are from a wildfire. It appears that the SC&A protocol isn't sensitive enough to determine if the majority of black particles in a sample are combustion or non-combustion particles.

This study demonstrated that false positives and false negatives can dominate the results of a SC&A analysis. The chart on page 20 shows that values of 5% SC&A are possible when the presence of the wildfire assemblage is absent. It also shows that values of 5% or less SC&A are possible when the wildfire assemblage is present at high levels. The problem begins with the poor definition of what constitutes the SC&A particles. Quantification is the next problem. How the percentage of those particles attributed to wildfire in each field of view are integrated across those fields and the sample as a whole into an estimated percentage of the total particle area is no easy task. No testable procedure is provided except for the counting methods that suffer from the diverse size problem.

The quantification criteria for exposure used in the assemblage analysis method is independent of other particles that may be on the surface sampled. It often requires that a surface area in excess of that used for SC&A analysis be used in order to determine that there has been no exposure. SC&A analysis often reports exposure to wildfire smoke when assemblage analysis finds no exposure to that wildfire because combustion products and other black particles are always present indoors, even without exposure to a wildfire. SC&A analysis can also under estimate the amount of combustion particles because the quantification procedure used relates the amount of suspected black combustion particles to the total particle population in the sample.

A requirement for assemblage analysis is that the prepared sample must be of high optical quality. The tape used has a cellulose ester plastic film with an acrylic adhesive. Acetone is then used to remove the plastic film and a resin approximately matching the acrylic adhesive's refractive index is applied along with a glass coverslip.

The use of clear tape where the plastic is not removed doesn't have sufficient optical quality for this type of analysis. The sample typically used for SC&A analysis is of inferior quality. That significantly limits the confidence in the identification of specific particles.

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