Presentation given at the workshop:
Working together- Fire managers & archaeologists
November 27-29, 2018:
Organized by the Southwest Fire Science Consortium
https://www.swfireconsortium.org/2018/06/26/november-27-29-2018-working-together-fire-managers-archaeologists/

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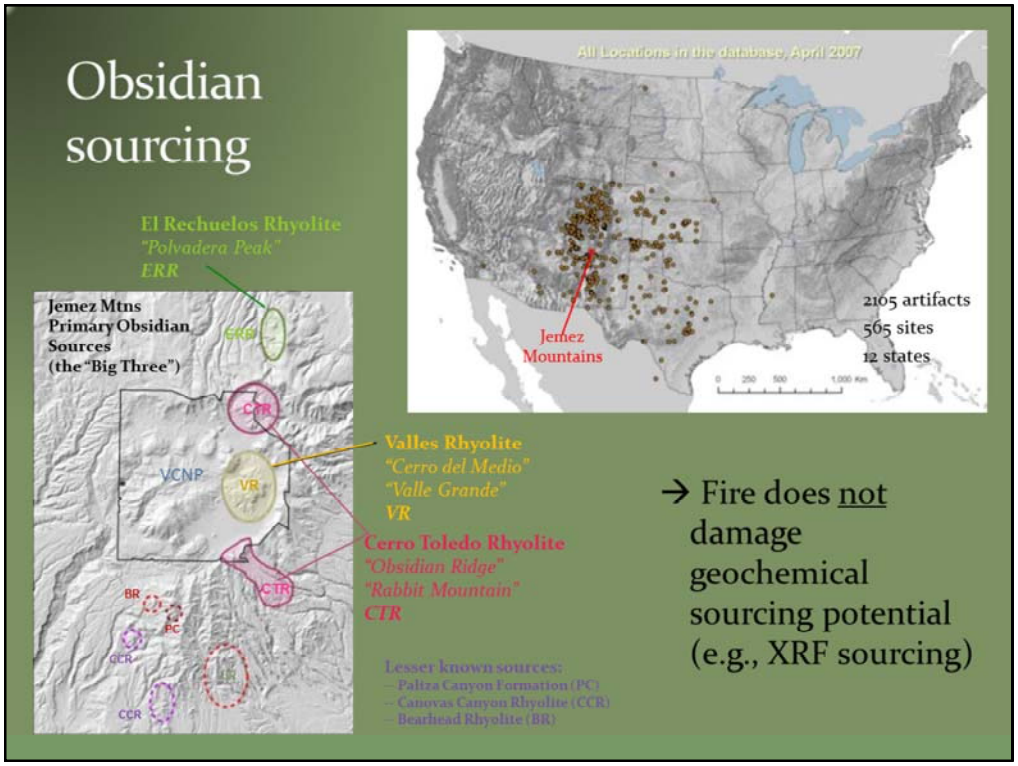
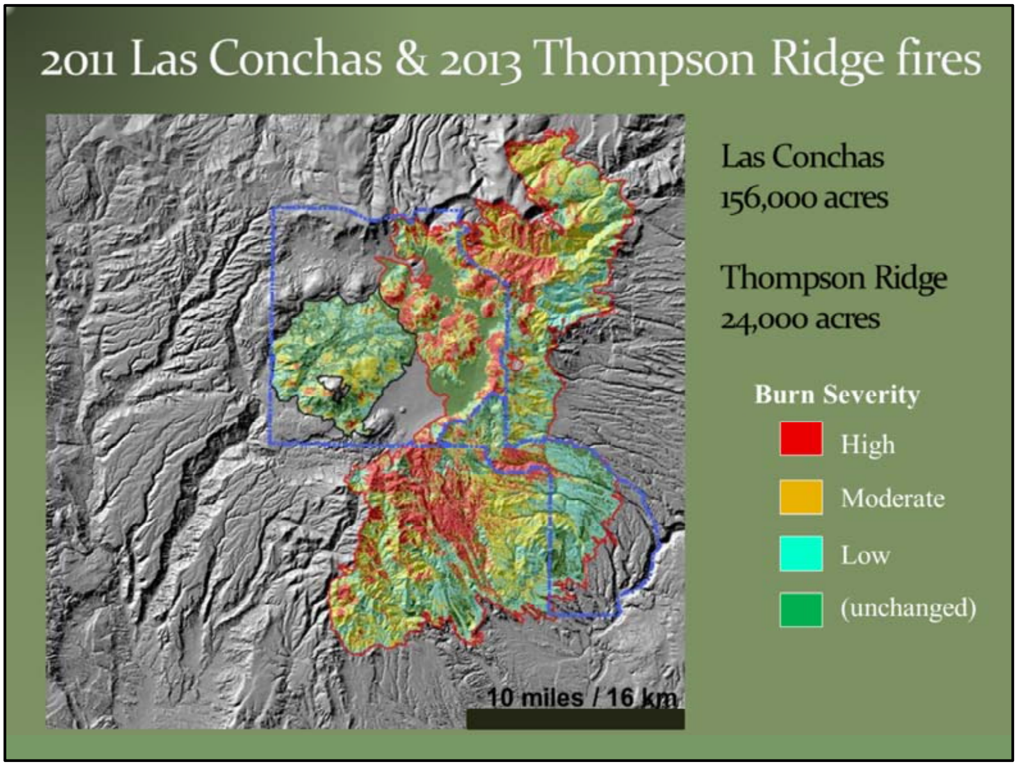
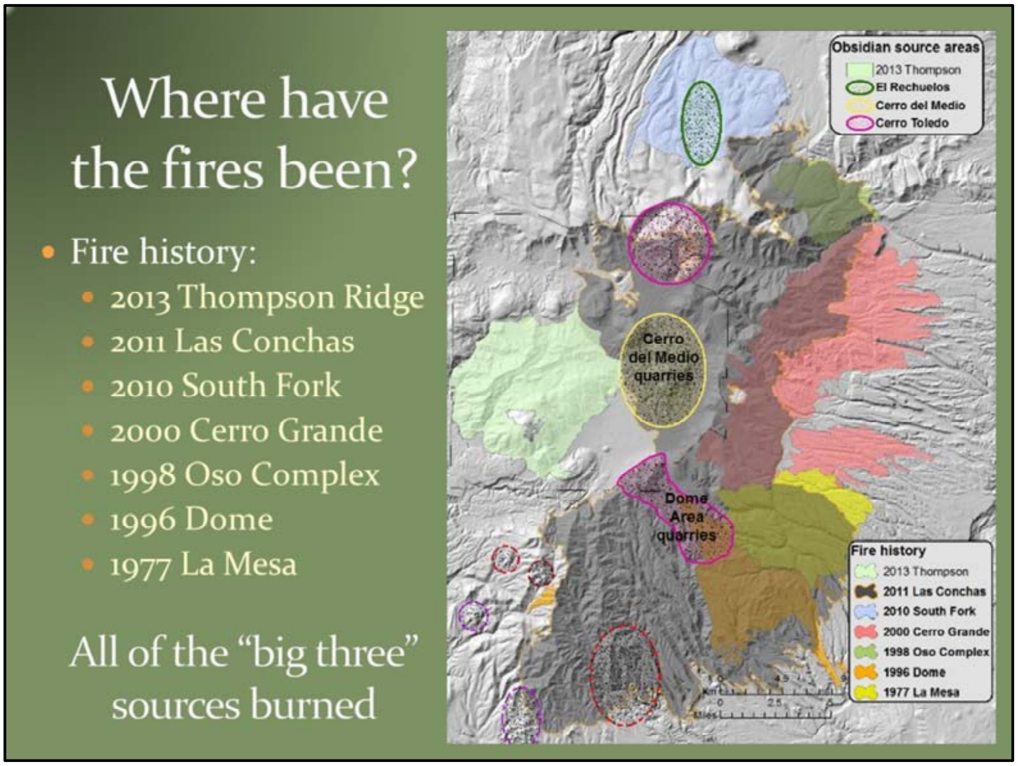
Please contact Ana Steffen: ana_steffen@nps.gov 575-829-4859



The initial study area for the definition of obsidian fire effects was in north-central New Mexico in the Jemez Mountains following the 1996 Dome Fire.
Upper right: Jemez Mountains obsidian materials are found as artifacts across the center of the U.S. (not just in the Jemez Mountains)
Obsidian fire effects likely vary somewhat in different geologic source areas.

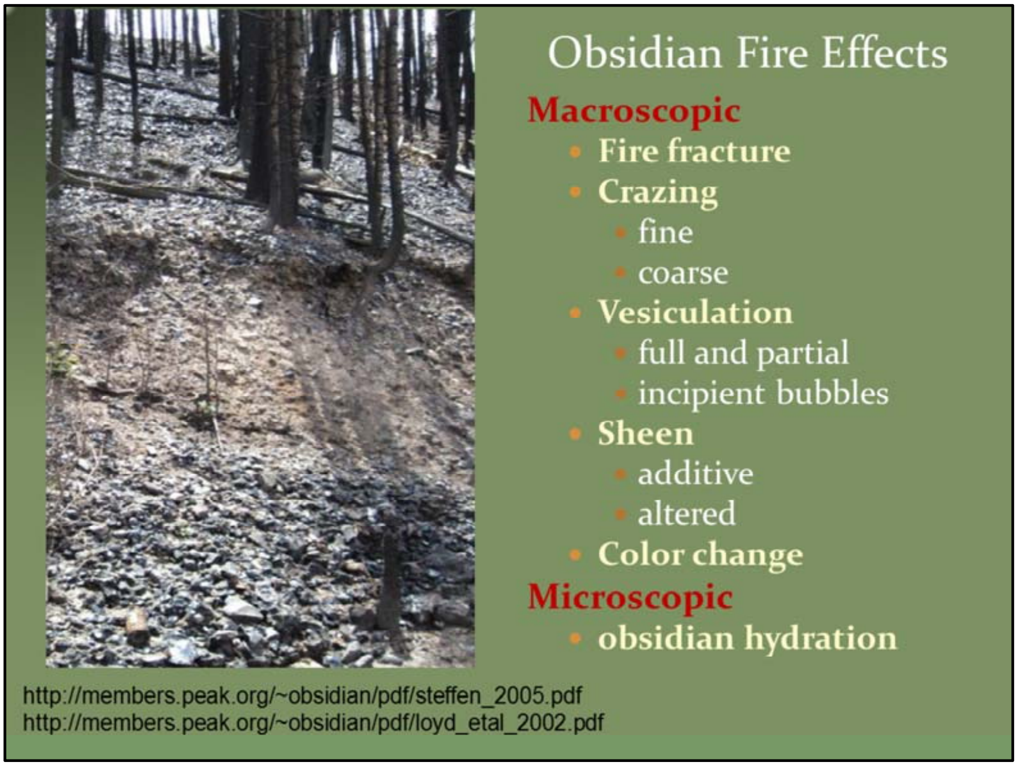


2011 Las Conchas Fire and 2013 Thompson Ridge Fire areas and burn severity



Areas with obsidian sources include Valles Caldera National Preserve, Santa Fe National Forest, and Bandelier National Monument.

To-date, it is likely that >80% of the Big Three obsidian source areas in the Jemez Mountains have been affected by forest fires in the last few decades.



List of macroscopic fire effects to be discussed in this presentation.

For the origin of this list, see Steffen 2005 (SEE ALSO Steffen 2002, for an earlier version)

Steffen, Anastasia
2005 *The Dome Fire Obsidian Study: Investigating the Interaction of Heat, Hydration, & Glass Geochemistry.* Ph.D. dissertation, Department of Anthropology, University of New Mexico, Albuquerque. http://members.peak.org/~obsidian/pdf/steffen_2005.pdf

Steffen, Anastasia
2002 The Dome Fire Pilot Project: Extreme Obsidian Fire Effects in the Jemez Mountains. In *The Effects of Fire/Heat on Obsidian,* edited by J. M. Loyd, T. M. Origer, and D. A. Fredrickson, pp. 159-201. US-DOI, BLM Cultural Resources Publication, Anthropology - Fire History.
http://members.peak.org/~obsidian/pdf/loyd_etal_2002.pdf
http://members.peak.org/~obsidian/pdf/loyd_etal_erratum_2002.pdf

Fire fracture describes rapid fracture through the body of the artifact or nodule that can look similar to intentional lithic reduction but that initiates from within the item rather than at a margin or edge from an externally applied force.

Whether fire fracture is observed across an obsidian quarry / obsidian source exposure depends on the burn context and density of obsidian exposed to fire. Ground surfaces that are dense with obsidian cobbles are much more likely to express fracture—this is an intersection of several factors:
--likelihood (whether there are enough pieces available for the low-level effect to be expressed),
--observability (whether archaeological field personnel will detect the occurrence), and
--systematic attention (whether archaeologists are looking for it—which is higher in known quarries or other obsidian-dense surfaces).
Fire fracture is much more common in chunky nodules than in thin artifacts/flakes. Probably, fire fracture is more likely to occur in nodules that are generally unmodified since eruption (i.e., pieces previously fractured will have released an internal tension that if unreleased increases the likelihood of fire fracture.

An obsidian nodule fractured in the 1996 Dome Fire

Fire fractures look much like intentional human-induced fracture

Key differences:

--there is no flake/core relationship

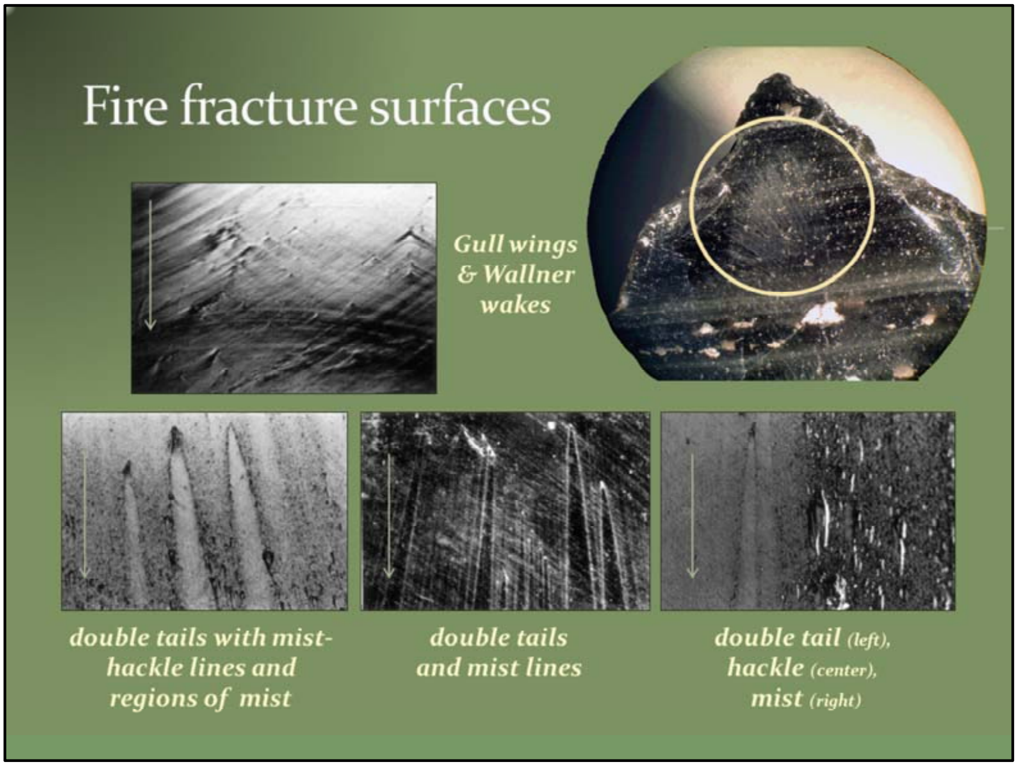
--lacking bulbs of percussion: because fracture not initiated by force at an edge

Visual cues:

--shape/geometry of fracture surface

--edges of fracture termination

--signatures of fracture progression on FF surfaces



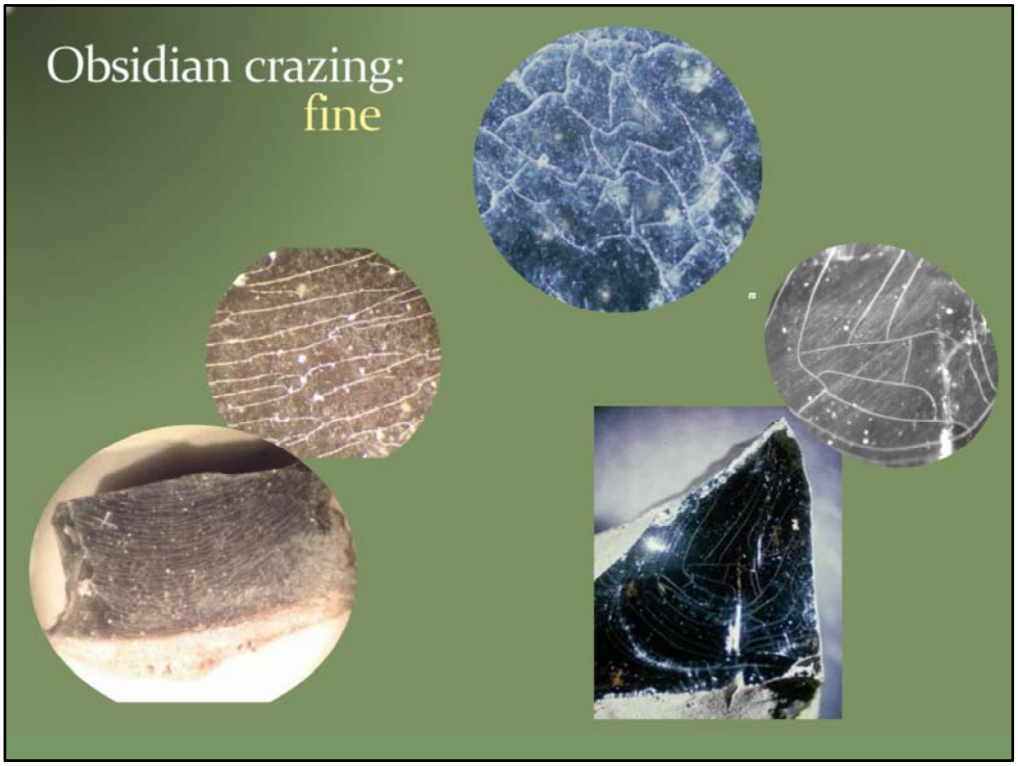
Signatures of fracture progression on FF surfaces

--Fractures caused by heat exposure occur at a much more-rapid speed than intentional / human-caused fracture (i.e., knapping fractures).

--Fractographers (i.e., Are Tsirk) can identify several characteristic features of high-speed fracture that can be observed on obsidian fire fracture surfaces but are not visible on knapping flake/core surfaces. –

--These surface characteristics can be used effectively as "diagnostic" for distinguishing between fire fracture pieces and actual artifacts (i.e., the debitage/cores/tested-nodules found at obsidian quarry sites).

Note: circled area shows the location of mist-hackle lines in FF surface; this piece was shown in the prior slide (right-hand side of right-hand image)



Fine crazing describes a delicate network of shallow cracks on fresh fractures or artifact surfaces

The crazing occurs across entire individual surfaces, but not necessarily on all of the specimen's surfaces.

The crazing observed on burned obsidian is quite unlike the kind of crazing that occurs on burned chert artifacts. Obsidian crazing is extremely shallow and is clearly a phenomenon that occurs **only at the very surface**. By contrast, chert crazing is caused by *internal* fracturing (including potlidding) expressed at the surface as cracking. The causes of fine crazing in obsidian are probably similar to the surface crazing seen in silica glazes on high-fire ceramics, and as such may be a result of cooling processes and/or differential thermal expansion rather than the kind of material failure observed in chert crazing.

Fine crazing in burned obsidian overlaps somewhat in appearance with radial fracture lines that develop during detachment from a core. However, obsidian crazing can be readily distinguished from radial lines because crazing forms a network of interlocking or closed polygons and radial lines do not.

Coarse crazing: Deep surface cracking describes artifact surfaces that are split by shallow crevices that extend below the immediate surface of the artifact. These cracks are deeper than fine crazing and create a roughened surface that can be detected tactilely.

Deep or coarse crazing is almost certainly an extension of fine crazing, i.e., an effect subsequent to fine surface crazing. This often occurs in conjunction with deformation of the artifact, such as by vesiculation.

Vesiculation is expressed as the formation of abundant and interconnected bubbles throughout the interior and at the surface of the glass object as a result of heating. This formation of bubbles often causes deformation (bloating) and an increase in object volume or size.

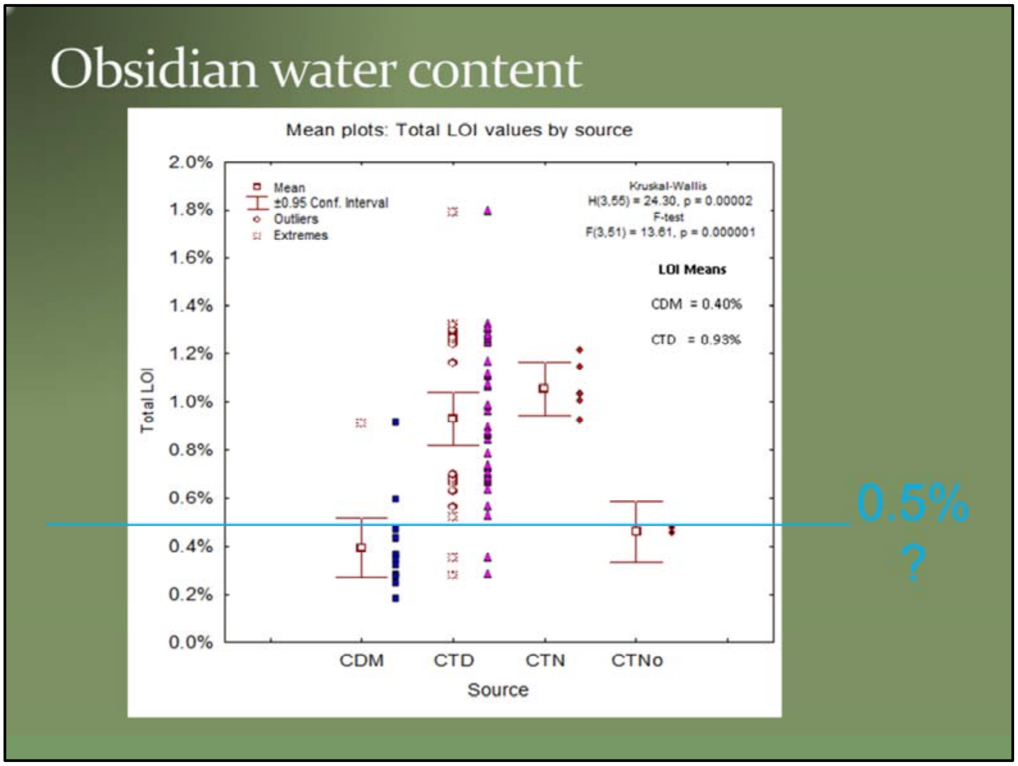
"Vesiculation" is the term introduced to fire effects literature by Trembour (1979, 1990). As used here, "vesiculation" refers to vesicles in obsidian created as a response to heat exposure unrelated to the original (volcanic) formation of the clasts.

Trembour, Fred. W.
1990 Appendix F. A Hydration Study of Obsidian Artifacts, Burnt vs. Unburnt by the La Mesa Fire. In *The 1977 La Mesa Fire Study: An Investigation of Fire and Fire Suppression Impact on Cultural Resources in Bandelier National Monument*, edited by D. Traylor, L. Hubbell, N. Wood, and B. Fiedler, pp. 174-190. Southwest Cultural Resources Center Professional Paper No. 28.

Post-fire detection in the field is enhanced when surveying ASAP after the fire: the white of the vesiculation stands out in clear contrast where there is still blackened-ground and surface charcoal

Vesiculation can be partial or complete/full.

A vesiculated object is perceived as being lighter in weight, but this is an illusion caused by expansion of object size without an increase in weight.



Intrinsic water content (i.e., the water that was in the magma and retained in the glass) almost certainly increases the likelihood of obsidian to vesiculate.

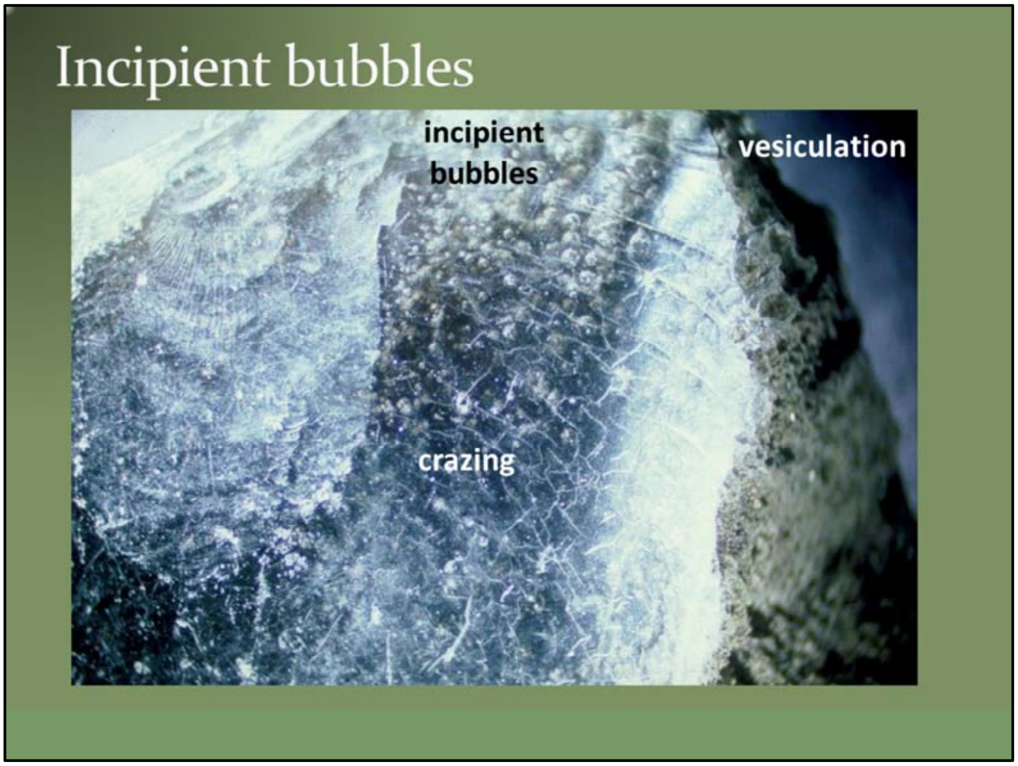
Graph shows water content measures at Cerro del Medio (CDM), and two areas within Cerro Toledo Rhyolite (CTD, CTN), as well as one previously unidentified source in the Jemez Mountains (CTNo).

The main Cerro Toledo source areas (CTD) have obsidians with water contents measuring ~0.3 – 1.3%.

This is at odds with the 0.5% value for water content frequently found in the archaeological literature on obsidian hydration dating.

High water content here is probably the reason the glasses vesiculated in the 1977 La Mesa Fire, 1996 Dome Fire, and 2011 Las Conchas Fire.
However, vesiculation has been found at other obsidian source areas, just not in such abundance.

Steffen, Anastasia
2005 *The Dome Fire Obsidian Study: Investigating the Interaction of Heat, Hydration, & Glass Geochemistry.* Ph.D. dissertation, Department of Anthropology, University of New Mexico, Albuquerque. http://members.peak.org/~obsidian/pdf/steffen_2005.pdf



Incipient bubbles describe individual bubbles that have developed below the subsurface, but without the abundance, density, and interconnectedness of vesiculation. There is no appreciable deformation because the internal bubbles are not developed sufficiently to compromise the shape of the glass matrix. Incipient bubbles can be thought of as a subset of vesiculation (or, as incomplete vesiculation).

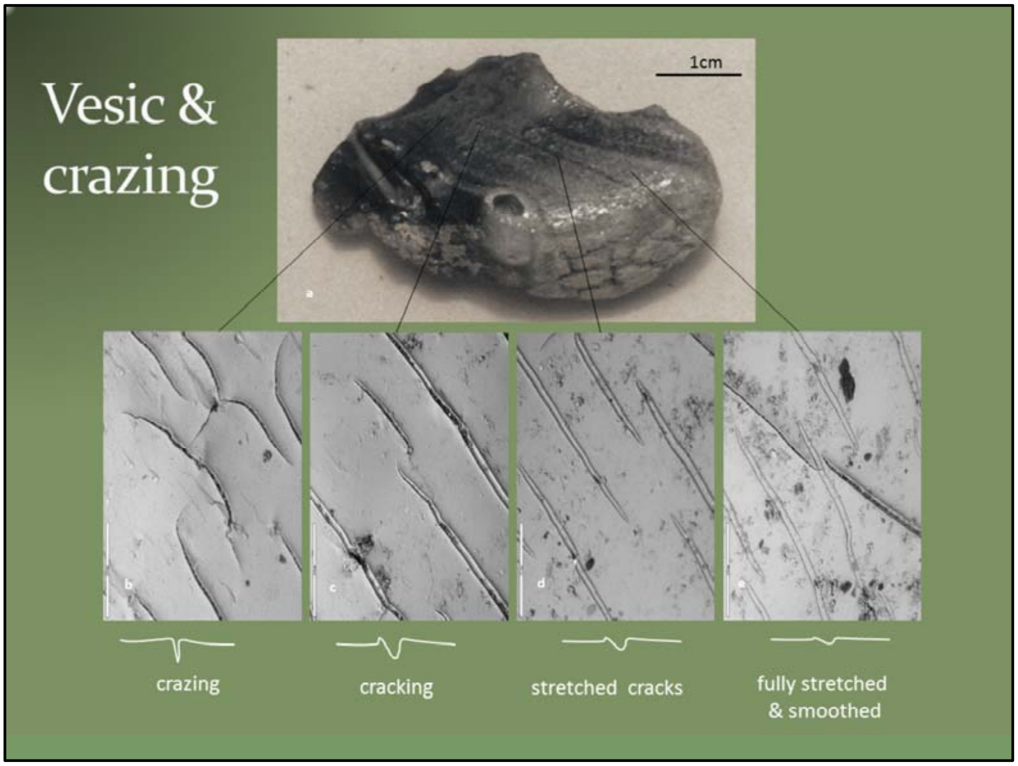
These subsurface bubbles are observed more frequently in clear obsidian than in cloudy or opaque obsidian, perhaps because subsurface bubbles are easier to see when the glass is more transparent, and can be more readily apparent when there is light transmitted through translucent or semi-translucent glass.

For both incipient bubbles and vesiculation, it may be that cloudy glasses contain more precursors for bubble formation (e.g., internal inclusions such as microlites, phenocrysts, or zenolith particles). In other words, if cloudy materials have more loci for bubble nucleation, the result would be more and smaller bubbles. Under conditions leading to vesicle formation, more loci for bubble formation may predispose a specimen to vesiculation rather than the more “incomplete” alteration represented by incipient bubbles.

Note: this specimen also has crazing

Incipient bubbles have been observed to follow banding or other characteristics visible in the glass, lending support to the inference that the formation of bubbles is influenced by compositional or textural characteristics of the glass. This observation was an important influence in examining possible compositional causes for variable expression of vesiculation in obsidians found in the Cerro Toledo Rhyolite deposits affected by the Dome Fire.

Note: this specimen also has crazing

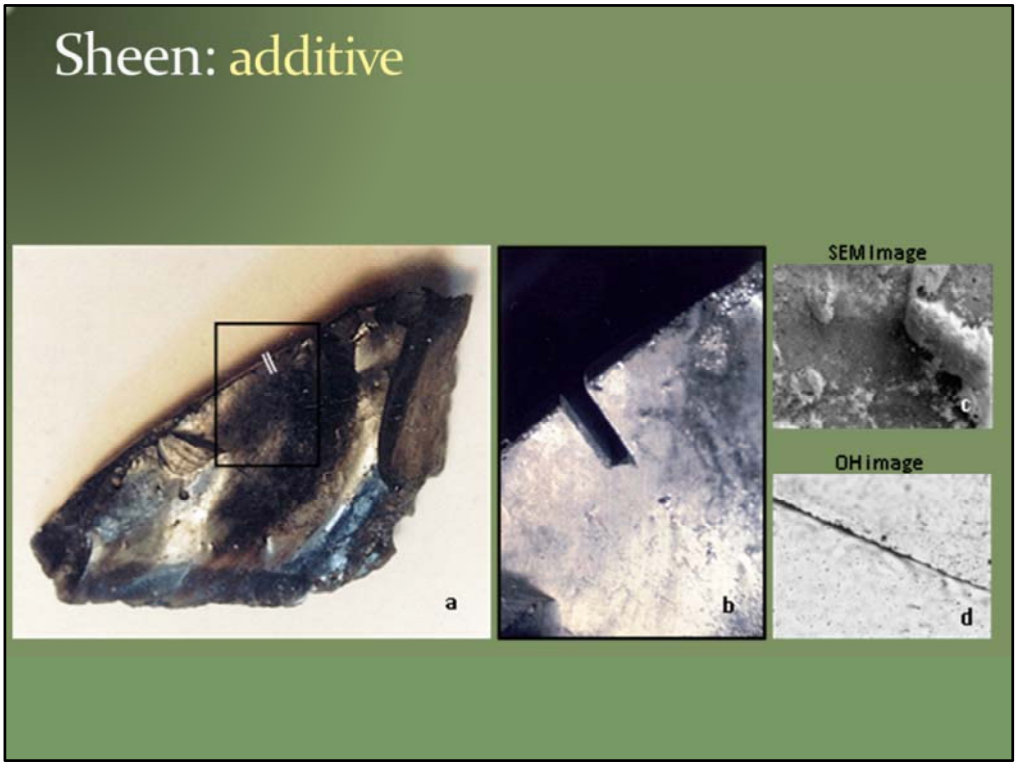


Transformation of crazing from fine to coarse with modification of the object (in this case the cause of modification is bloating from vesiculation).

The hand sample in the upper image is an artifact flake that had developed a crazed surface, and then partially vesiculated (with greater vesiculation on the right side of the flake).

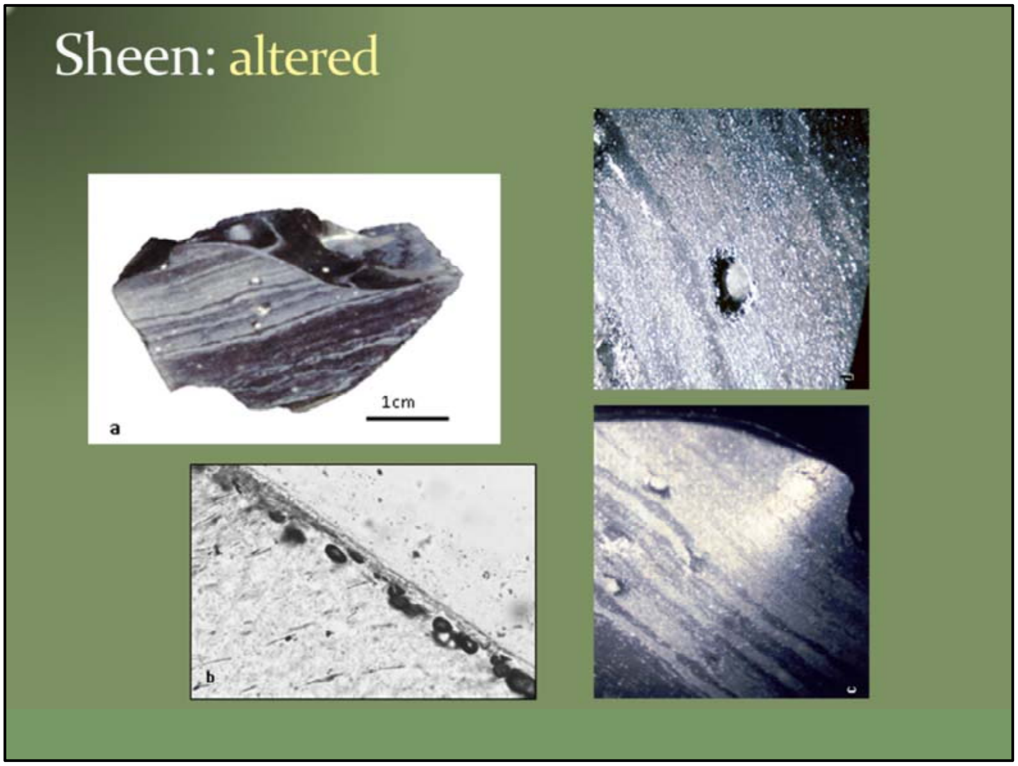
The scanning electron microscope images below the hand sample show that with increased bloating (left to right), fine crazing lines are deformed to create deeper cracking, and then subsequently stretched to become shallow and flatter/smoothed furrows.

The far-right image also shows new crevasses forming with extreme bloating.



Additive sheen has the characteristic "gun-metal" appearance commonly observed on burned obsidian. This additive material is a coating or residue from combustion of fuels in the area of the obsidian object.

Additive surface sheen:
(a) complete specimen 1691-1 (photo taken prior to OHD cut);
(b) close-up showing optical magnification of sheen at location of OHD cut on specimen edge (note tarry globules visible in upper right);
(c) secondary-electron image of residue on artifact surface (no scale recorded for this SEM image which was obtained at 500x magnification);
(d) an obsidian hydration cross-section shows no visible hydration and weathering or residue on exterior of obsidian surface: the obsidian side is located in lower left while the upper right is the resin matrix of the OH slide (no magnification recorded for OH images, normal light, photography by T. Origer).



Altered sheen evidences a change in the reflective properties of the glass surface caused by physical alteration of the surface by shallow (<10 microns) crazing and, in some cases, the formation of very small bubbles just below the surface. Altered sheen is more silvery and reflective in appearance than altered sheen, and has a crinkly texture rather than the smoother burnished appearance of additive sheen.

Altered sheen can have a banded appearance to it, which appears to be an exaggerated version of the internal banding within the glass. This characteristic suggests that banding in altered sheen is expressing differential composition or textural characteristics in the glass—or even more likely, that the glass has differentially adsorbed water of hydration that variably affects the tendency to vesiculate in that layer of surface hydration. This surmise has not been tested in the lab.

Altered surface sheen, which appears as banding due to variability within the glass:
(a) artifact specimen 1691-12;
(b) OH image showing small bubbles below surface of glass (no scale, normal light, photography by T. Origer);
(c) close up of sheen surface (originally 10x magnification);
(d) further close up of sheen surface showing irregular texture of surface, and spalling at inclusion where "sheen surface" has been lost leaving unaltered glass (originally 25x magnification).

Color alteration: undefined and not well understood…..

The original obsidian of this flake was fully opaque and black/brown (lower right).
Clear areas on the left and upper parts of the flake show transformation to clear color and increased translucency caused by heat exposure. The clear areas also have vesiculation and incipient bubbles.

The cuts are where OHD samples were removed.

Further description: This a partially vesiculated flake that also has crazing and incipient bubbles. The artifact at first appears to be black opaque obsidian, but with transmitted light unusual colors in the flake can be observed. One half of the flake (nearest the vesiculated edge) is translucent and medium to light grey, while the other half of the flake is opaque and brown. There is no abrupt demarcation between these two visual variants within the glass; instead they grade into each other rapidly with some feathering of the opaque brown material into the translucent grey. While neither visual variant is uncommon in obsidian from this source, their combination on one flake is unusual and almost certainly is due to heat exposure on the upper left.


Well, this is certainly fascinating, but why is it important?

Classification matrix: assessing fire-caused alteration of archaeological materials (*is there loss of information?*)

Loss of information	Ceramics	Obsidian	Chert	Masonry
Identification: Is the object less recognizable or no longer recognizable as an artifact?	Spalling and fracture; residue deposits; melting	Vesiculation, fracture	Spalling, fracture	Fracture
Form: Is the artifact shape or form altered?	Fracture; melting; loss of paint	Vesiculation, fracture	Spalling, fracture	Fracture, cracking, spalling
Material: Is the base chemical or mineral structure of the artifact altered?	Alterations to core; temper	Glass color change, sheen, vesiculation	Color change, crazing	Color change
Technology: Is information lost on how or where the artifact was manufactured?	Change in temper; surface or core color; core pattern; obscured surfaces	Fracture, vesiculation (loss of flake shape, platforms, & dorsal scars)	Spalling, fracture	Fracture, spalling
Provenance: Do fire effects interfere with identification of material sources?	Change in temper; core color	Vesiculation, glass color change *(XRF sourcing is not affected)*	Color change	
Chronometry: Does fire alter the relative or absolute chronometric dating potential of the artifact?	Change in paint or surface color, loss of paint; obscured surfaces; crazing; melting of glaze paint; core color or pattern change	Fracture, vesiculation, obsidian hydration alteration	Spalling, fracture	Fracture, cracking, spalling
Cultural Affiliation: Do fire effects alter characteristics that allow for identification of affiliation?	Change in paint or surface color, loss of paint; obscured surfaces	Fracture, vesiculation	Spalling, fracture	Fracture, cracking, spalling
Persistence: Is the artifact in a form that is durable following fire?	Fracture	Fracture, vesiculation	Fracture	Fracture, cracking, spalling

http://www.forestguild.org/Arcburn *Loehman et al. 2016 ARCBURN FINAL REPORT*

"LOI" Loss of information matrix from ArcBurn final report:

page 22: *Not all fire effects to artifacts include LOI. For example, sooting on artifacts may not persist indefinitely (i.e., the effects are reversible or diminish over time), or the obscuring effects of some surface residues may not interfere with documentation of key artifact characteristics such as material source. Sooting and additive sheen on obsidian were observed frequently in the experimental results, but are not significant in terms of loss of information. Other changes are permanent but of low relevance, such as oxidation and color change in masonry. Our assessment of relevance or non-relevance for information loss provides a stronger basis for prioritizing preservation measures and treatment actions.*

For obsidian:
Fire fracture causes LOI of **Identification**, most often because false flakes are produced.
Vesiculation can cause LOI of **Form**.
Material is little affected by heat exposure in obsidian (e.g., XRF results are not changed), except through vesiculation.
LOI for **Provenenace** is not affected because of the resistance of XRF, but some color changes and surface changes (sheen) could throw-off visual id of obsidian (…which isn't a good idea anyway….)
Technology is affected by fire fracture and by bloating from vesiculation
Loss/alteration of hydration and deformation of diagnostic projectile point shapes can cause LOI of **Chronometry.**
There can be LOI for **Cultural Affiliation** if diagnostic projectile forms or other artifact shapes are lost due to fracture or vesiculation.
The **Persistence** of an artifact can be severely compromised if the artifact is vesiculated.

--NOTE: Crazing does **not** cause LOI in any of these classes, but it can be an important indicator that an artifact has been affected by heat, and therefore may have compromised obsidian hydration bands.

Loehman, Rachel, Bret Butler, Jamie Civitello, Connie Constan, Jennifer Dyer, Zander Evans, Megan Friggens, Rebekah Kneifel, Jim Reardon, Madeline Scheintaub, and Anastasia Steffen
2016 *Final Report: ArcBurn: Linking Field-Based and Experimental Methods to Quantify, Predict, and Manage Fire Effects on Cultural Resources.* Submitted to the Joint Fire Science Program, Nov. 2016
http://www.forestguild.org/Arcburn

Classification matrix: assessing fire-caused alteration of archaeological materials (*is there loss of information?*)

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http://www.forestguild.org/Arcburn *Loehman et al. 2016 ARCBURN FINAL REPORT*

For obsidian:
Loss/alteration of hydration and deformation of diagnostic projectile point shapes can cause LOI of **Chronometry.**
--**Fracture and vesiculation:** loss of temporally-diagnostic artifact shape
--**Obsidian hydration alteration**: loss of obsidian hydration dating potential due to loss of OH bands or alteration of OH bands through diffusion. Once OH bands have been transformed (e.g. from a long-ago fire) they will not re-hydrate in the manner assumed by normal OH dating methodology. All artifacts known to be affected by past fire (i.e., those displaying crazing, altered sheen, or fire-fracture) should be considered "suspect" and included in OH dating analysis only with great care.

"LOI" Loss of information matrix is from:

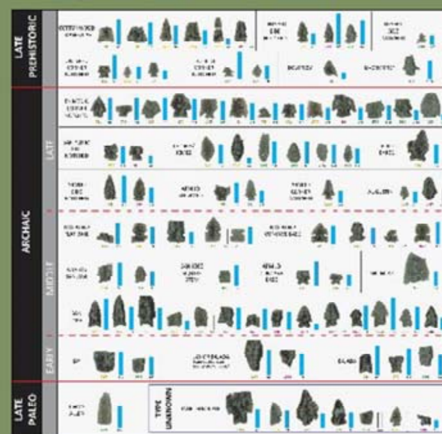
Loehman, Rachel, Bret Butler, Jamie Civitello, Connie Constan, Jennifer Dyer, Zander Evans, Megan Friggens, Rebekah Kneifel, Jim Reardon, Madeline Scheintaub, and Anastasia Steffen
2016 *Final Report: ArcBurn: Linking Field-Based and Experimental Methods to Quantify, Predict, and Manage Fire Effects on Cultural Resources.* Submitted to the Joint Fire Science Program, Nov. 2016 http://www.forestguild.org/Arcburn

Obsidian hydration dating

- Slow adsorption of water into glass surface
  - Older = deeper hydration
  - Younger = shallower hydration

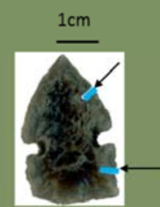
Fire can
alter / damage
hydration

Diagnostic projectile points

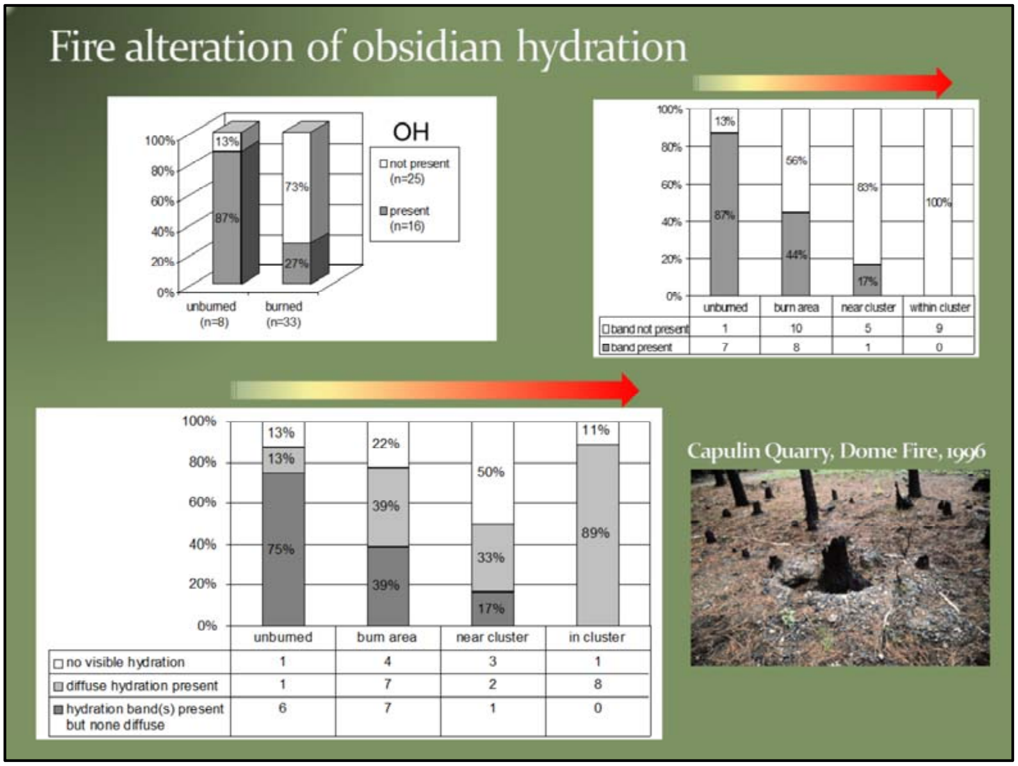


Obsidian hydration dating

- Fire can damage hydration
  - loss of OH bands
  - diffuse hydration



- Can use hydration to examine:
  - Relative age of artifacts
  - Soil mixing/disturbance
  - Fire/heat exposure

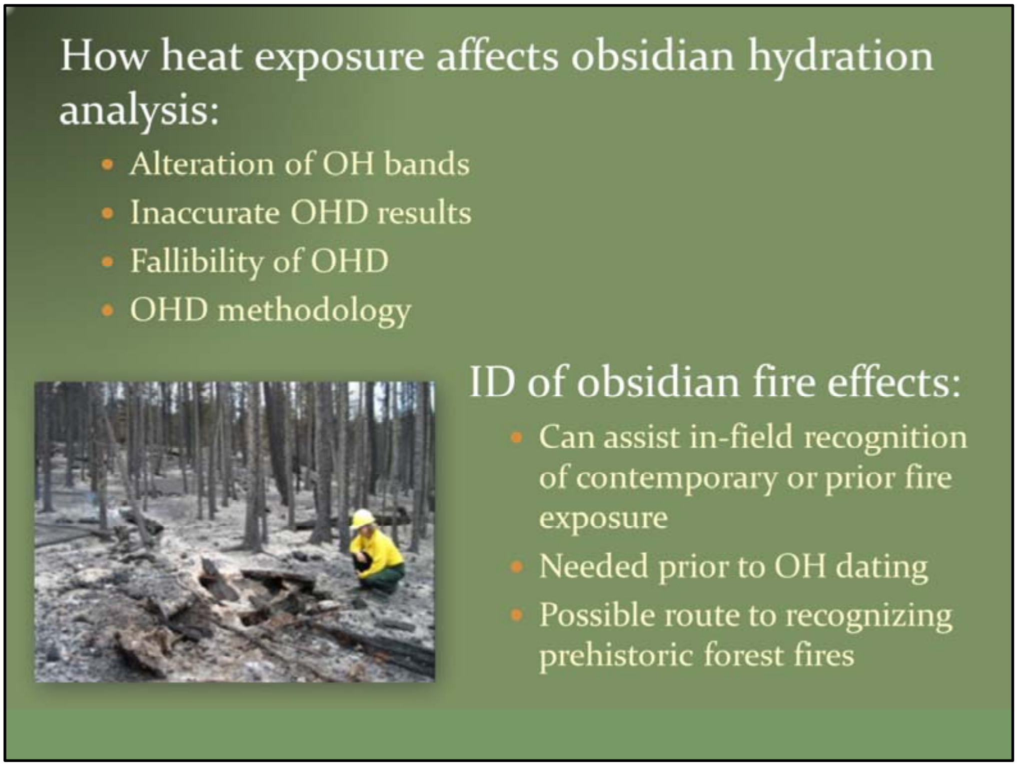


Analysis of OH band loss at Capulin quarries: unburned vs general burn area vs. near to clusters vs. inside cluster
Image: a cluster of vesiculated obsidian (commonly at burn stumps);
Upper left graph: Present/absence of intact and unaltered hydration bands on artifacts from unburned areas vs. burned areas;
Upper right graph: Distribution of intact/measurable hydration bands by degree of burning;
Lower graph (further details): Distribution of diffuse hydration bands by degree of burning (NVB vs. diffuse bands vs. intact bands)

Upper graphs: Loss/alteration of measurable hydration increases with proximity to areas of high intensity burning (as indicated by clusters of vesiculated obsidian).

Lower graph: The proportion of diffuse hydration also increases with proximity to higher intensity burning.

Note: all graphs are depicting the same dataset.



Obsidian Hydration dating needs analysis of fire effects!
--**Alteration of OH band**s: heat exposure can alter OH dating; all of these fire effects can be clues that the specimen may be compromised and a poor candidate for OHD.
--**Inaccurate OHD results**: Overlooking heat-affected obsidian artifacts can contribute to poor OHD outcomes. Fire effects observed in single specimens can raise questions about the dating of the overall assemblage—be careful if fire effects are observed on any of the artifacts in your OH dating “pool”.
--**Fallibility of OHD:** OHD methodology must include both the routine examination of artifacts to detect fire effects AND better consideration of variation in water content within and among obsidian sources. It may be one reason why OHD seems to work with some obsidian sources but not with others.
--OHD Methodology;
→Leaving water content out of the “practice” of OHD undermines the effectiveness of the technique.
→All obsidian artifacts that are candidates for OH dating need to be examined for possible fire effects that can indicate their unsuitability for dating.
→The ability to discern past heat exposure can provide a window to detection of prehistoric fires.

This is the last slide