

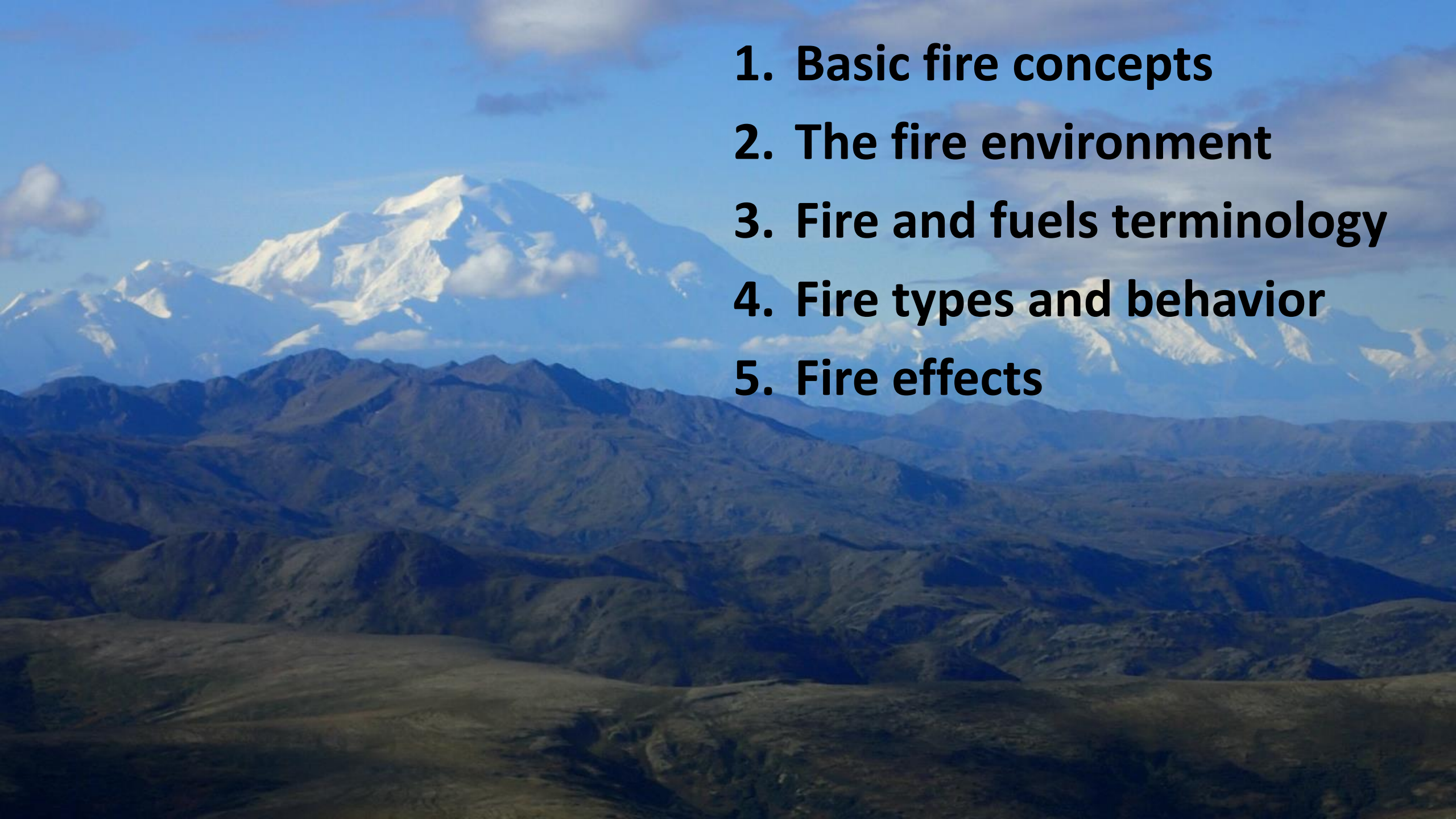


# Fire terminology, behavior, and effects: Principles for archaeologists

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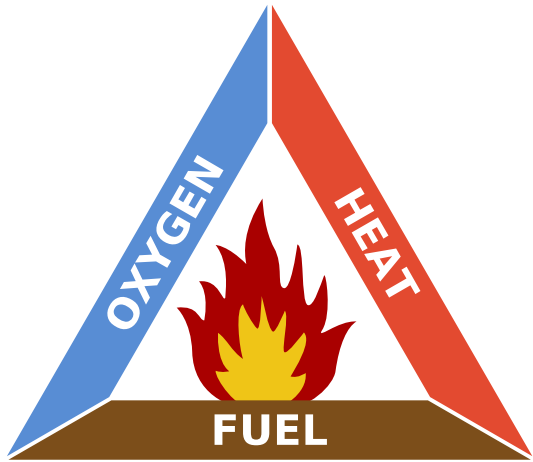
[rloehman@usgs.gov](mailto:rloehman@usgs.gov)



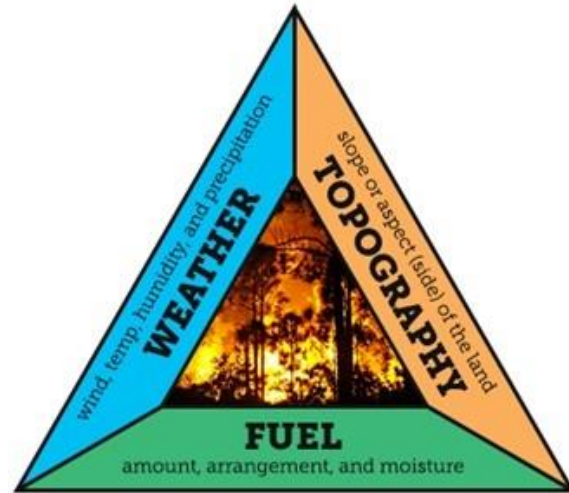
- 
- 1. Basic fire concepts**
  - 2. The fire environment**
  - 3. Fire and fuels terminology**
  - 4. Fire types and behavior**
  - 5. Fire effects**

# Basic fire concepts: Fire triangles

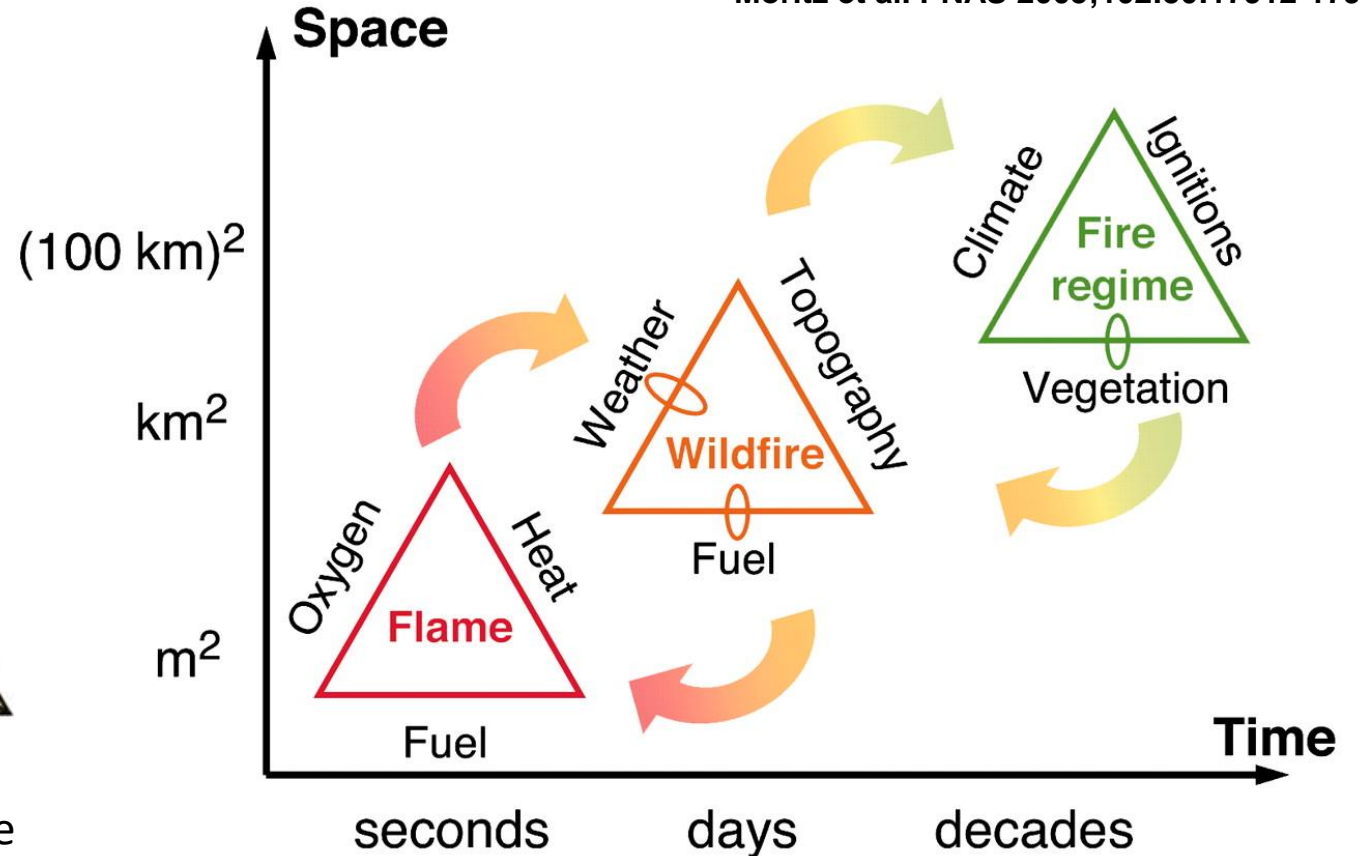
Moritz et al. PNAS 2005;102:50:17912-17917



Fire triangle:  
Necessary ingredients  
for fires to ignite and  
burn



Fire behavior triangle:  
Fire behavior depends on the  
amount and arrangement of  
fuel, the topography, and  
weather conditions  
(fire environment)



Fire regimes:  
Role of fire in ecosystems and interactions with  
dominant vegetation.  
Described by fire frequency, extent, intensity,  
severity, and seasonality

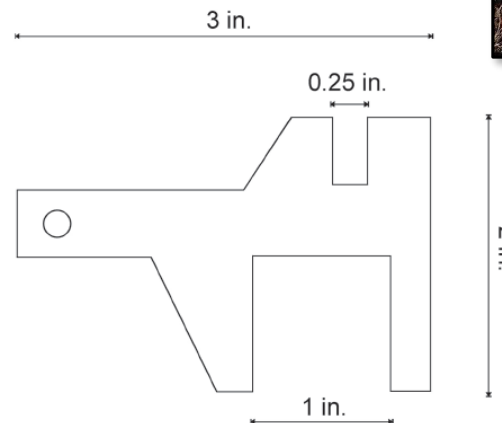
# Fire environment: Fuels

Fuel properties determine fire behavior and effects: how fires heat fuels and how much oxygen is in contact with fuels → how quickly fuels will ignite, how long they will burn, and resulting intensity.

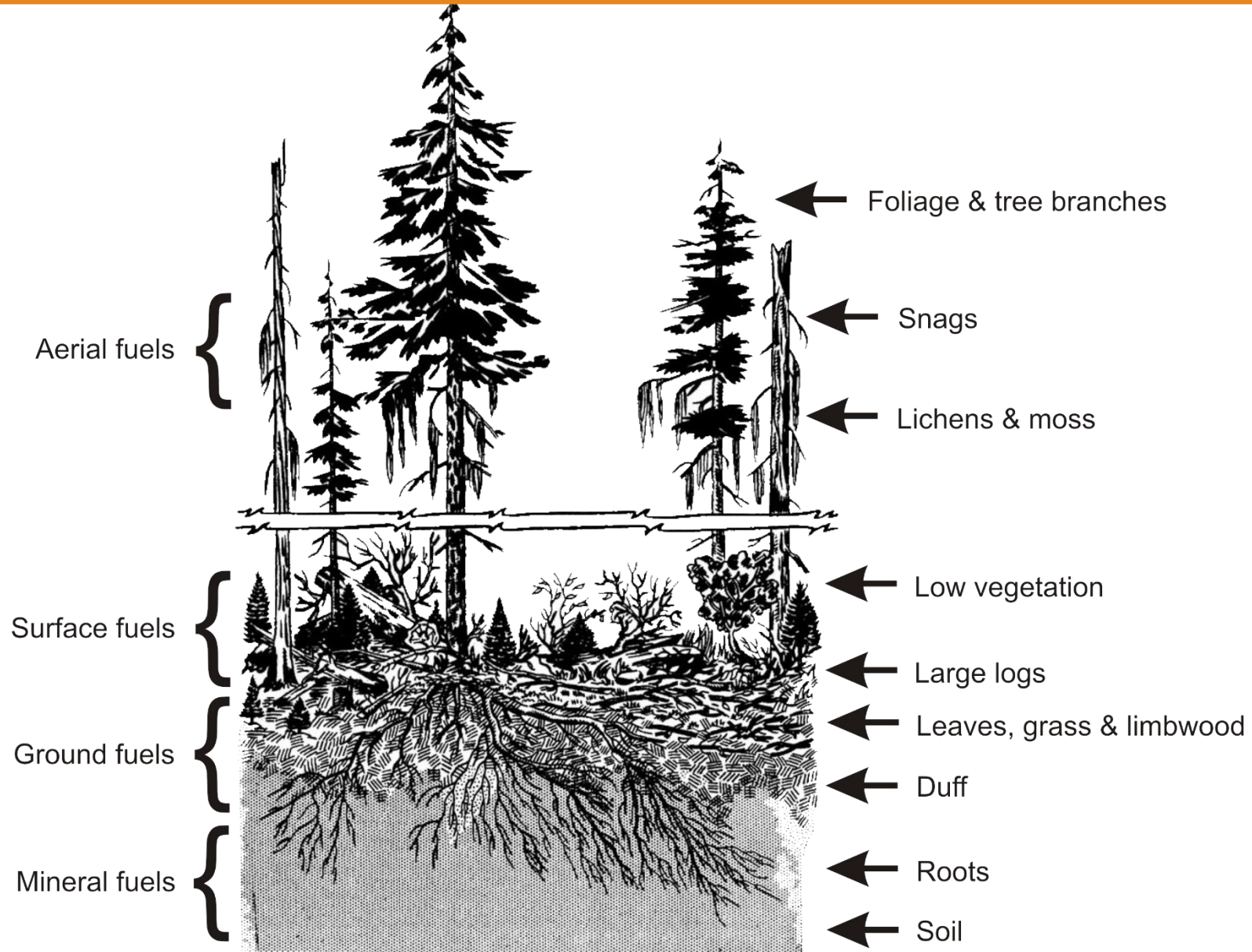
Important fuel properties that influence fire behavior:

- Size and shape – physical properties
- Moisture content – amt. H<sub>2</sub>O for given temp and RH
- Quantity (loading)
- Spatial arrangement (vertical and horizontal)

Dead woody class		Piece diameter	Piece diameter	
		<i>inches</i>	<i>cm</i>	
DWD	FWD	1-hr	0–0.25	0–0.6
		10-hr	0.25–1.0	0.6–2.5
		100-hr	1.0–3.0	2.5–8.0
	CWD	1,000-hr and greater	3.0 and greater	8.0 and greater



# Fire environment: Fuels



# Fire environment: Topography and weather

Slope impacts fuel availability and moisture, thus rate of spread and flame length

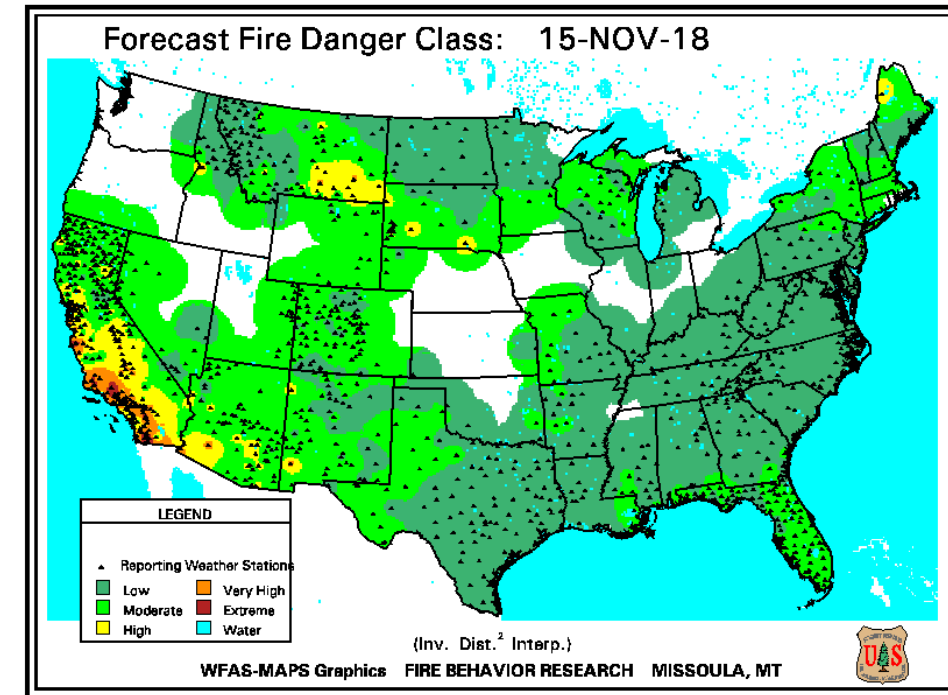
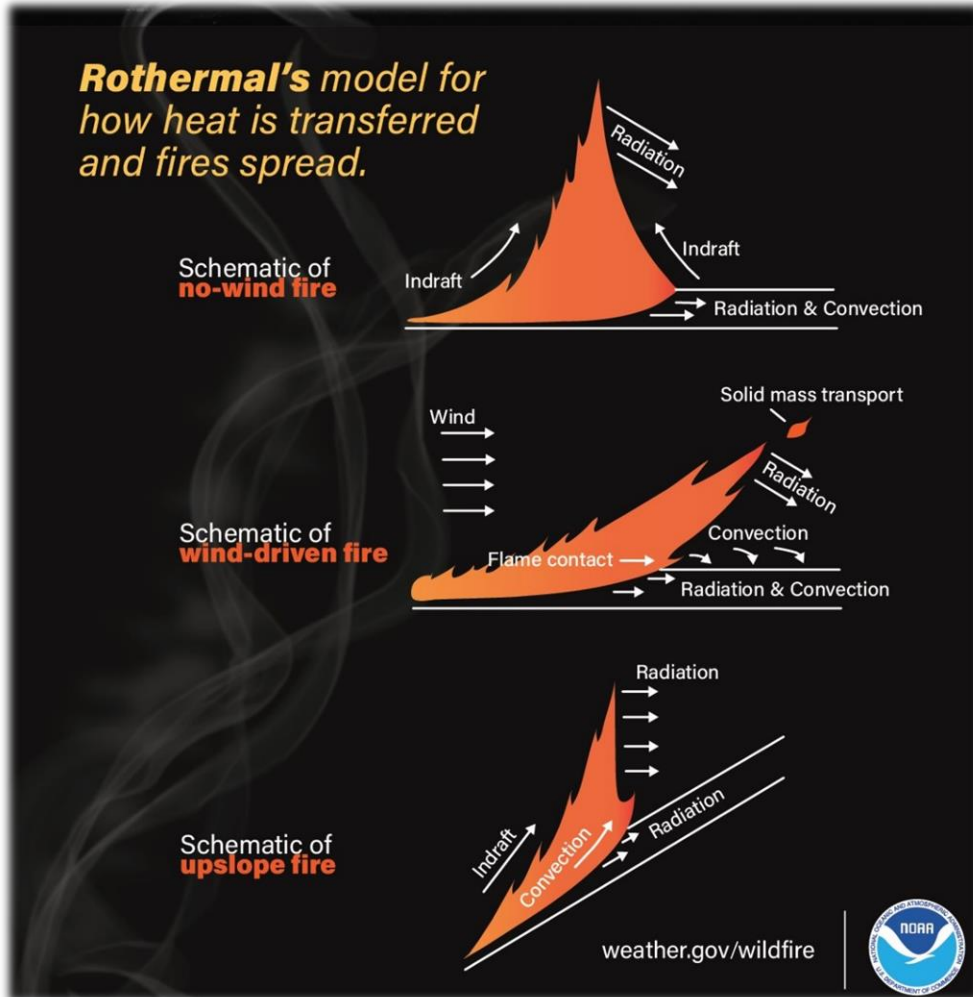
Weather defines amount of fuel available to burn

Long-term -

“Big picture” conditions – vegetation (fuel) type, amount, arrangement

Short-term –

Relative humidity (RH), temperature, winds regulate LIVE AND DEAD fuel moisture



For more information on fire weather -

<https://www.nifc.gov/nicc/predictive/predictive.htm>

<https://gacc.nifc.gov/swcc/predictive/outlooks/outlooks.htm>

# Fire terminology: Fire characteristics

**Fire regime** - role of fire in ecosystems

**Fire frequency** - mean number of fires per time period

**Fire extent** – size of fire

**Fire rotation** - time required to burn an area equal to a defined area of the landscape.

**Fire intensity** - measure of the heat energy released by a fire

**Fire severity** - net ecological impact

**Seasonal timing** – Occurrence in year

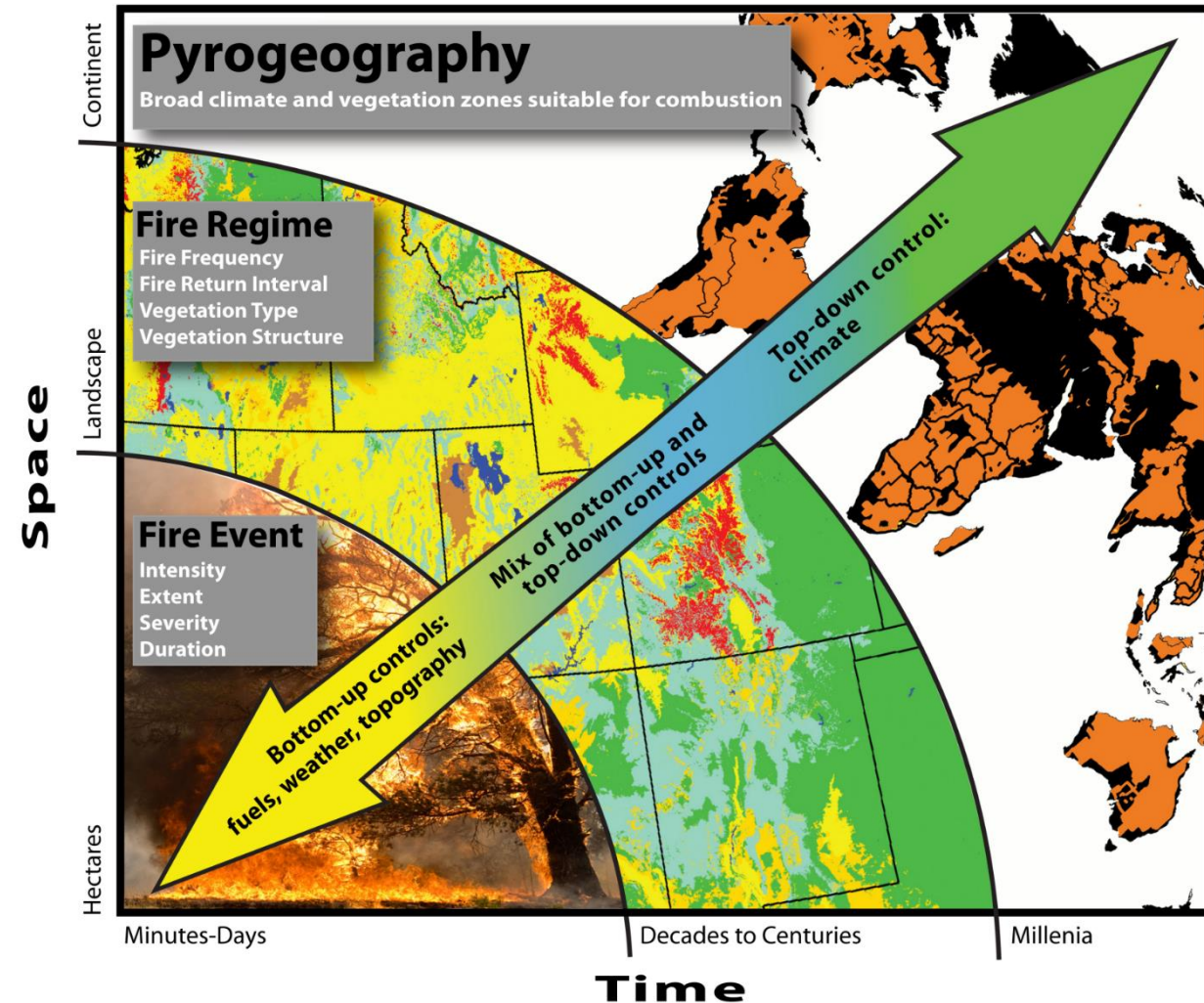
**Source of ignition** – lightning or human

For more definitions:

<https://www.nwccg.gov/glossary/a-z>

For more info on fire: <https://www.nifc.gov/>

Loehman et al. 2014, Forest Ecology and Management 317: 9-19.



# Fire terminology: Fire behavior and fire types

**Rate of spread** - rate of forward spread of the fire front, usually in chains or acres per hour

**Flame length** - distance from the ground to the **flame** tip

**Torching**—movement of a surface fire up into tree crowns; the precursor to crowning

**Crowning**—active fire movement through the tree canopy

**Spotting**—glowing embers lofted up and ahead of the main fire front that ignite spot fires

**Ground fire** –Fire that burns in the organic material below the litter layer, mostly by smoldering combustion

**Surface fire** –Fire that burns in litter and other fuels at or near the surface of the ground, mostly by flaming combustion

**Crown fire** - Fire that has ascended from the ground into the forest canopy

For more info on fire behavior and fire ecology –

<https://www.frames.gov/partner-sites/fireworks/fireworks-home/>





# Ground Fire

Burns by smoldering combustion

Low energy release rates, long duration, and often by *deep* soil heating.

Ground fuels burn after the flaming front passes, with temperatures over **400°C (752°F)** for **3 to 30 hours** (or more).

Cultural resources in the duff and near the mineral soil surface can be **significantly** impacted in ground fires with dry duff.

If ground fuels are too wet to burn, *only top 3cm or so* of soil will be heated, even in an intense crown fire.



# Creeping Surface Fire

Low rates of spread, low energy release, low flame lengths (25cm), and short duration (3 minutes or so, except for logs).

In forests, smoldering in dry duff keeps fires going.

Temperatures can reach **500°C** (**932°F**).

Because fuel consumption is patchy, effects to cultural resources will be variable.



# Active Surface Fire

Few unburned patches, low but continuous rates of spread, moderate flame lengths (1/4m to 1.5m), and short duration (5 minutes or so, except for woody fuel concentrations).

500°C (932°F), can reach 700°C (1292°F) for short periods of time.

Cultural resources in flaming zone will be impacted, and those **one meter** away will be visibly altered.



# Running Active Surface Fire

Rapid rates of spread, very few unburned patches, flame lengths of 1.5 to 4m, and short duration (5 minutes or so, except for wood fuel concentrations).

**500°C (932°F)**, but can reach **800°C (1472°F)** for short periods of time

Substantial heat effects, with heat damage occurring to resources up to **4 meters** beyond the burned area.



# Crown Fire

Characterized by very rapid rates of spread, flame lengths over 10m

Flaming in the crown will last about one minute, but residual burning in the order of **5 minutes** is common

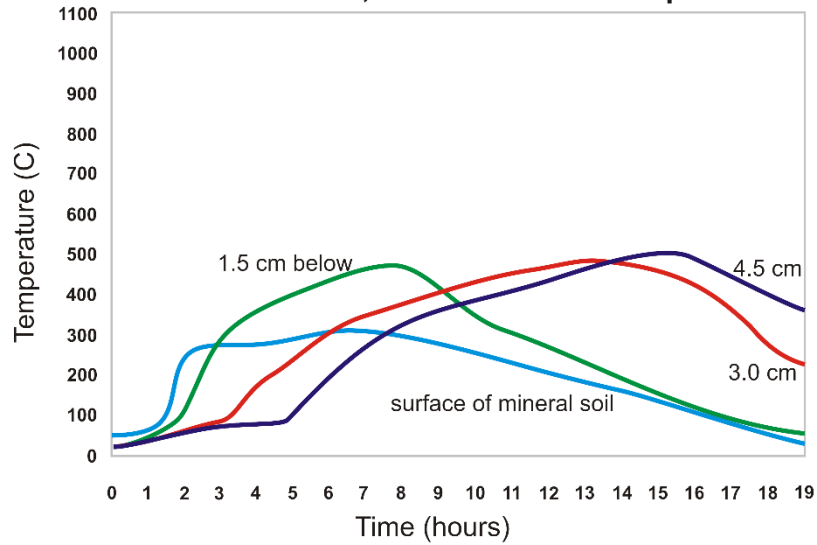
Temperatures in excess of **1500°C (2732°F)** can occur, but more often they hover around **1000°C (1832°F)**

Cultural resources as far away as **30 meters** from the burned area can suffer heat damage

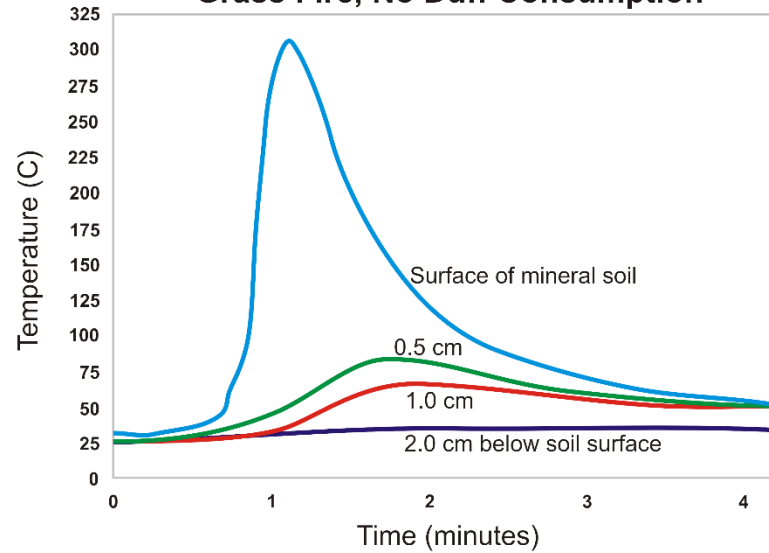


# Fire effects - Temperature and duration

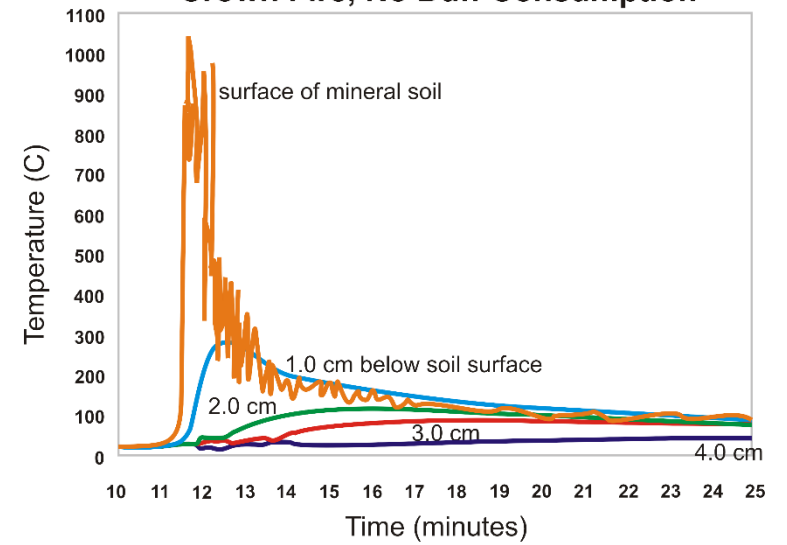
Ground Fire, Total Duff Consumption



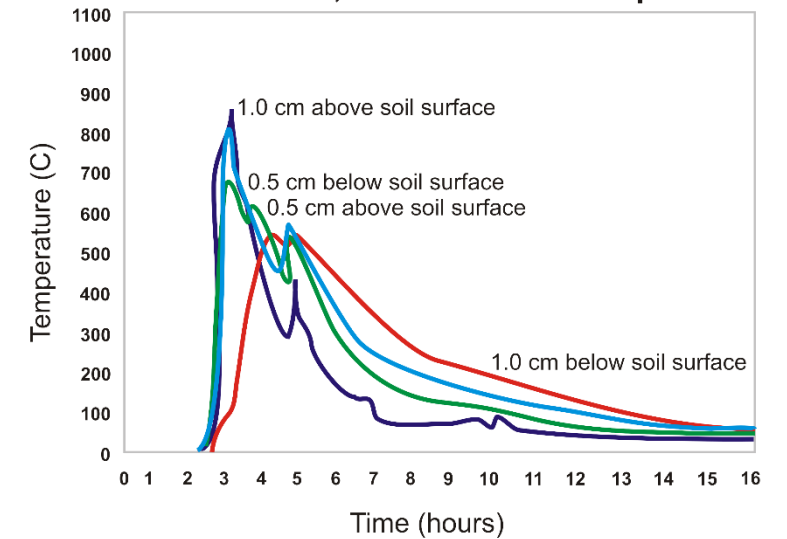
Grass Fire, No Duff Consumption



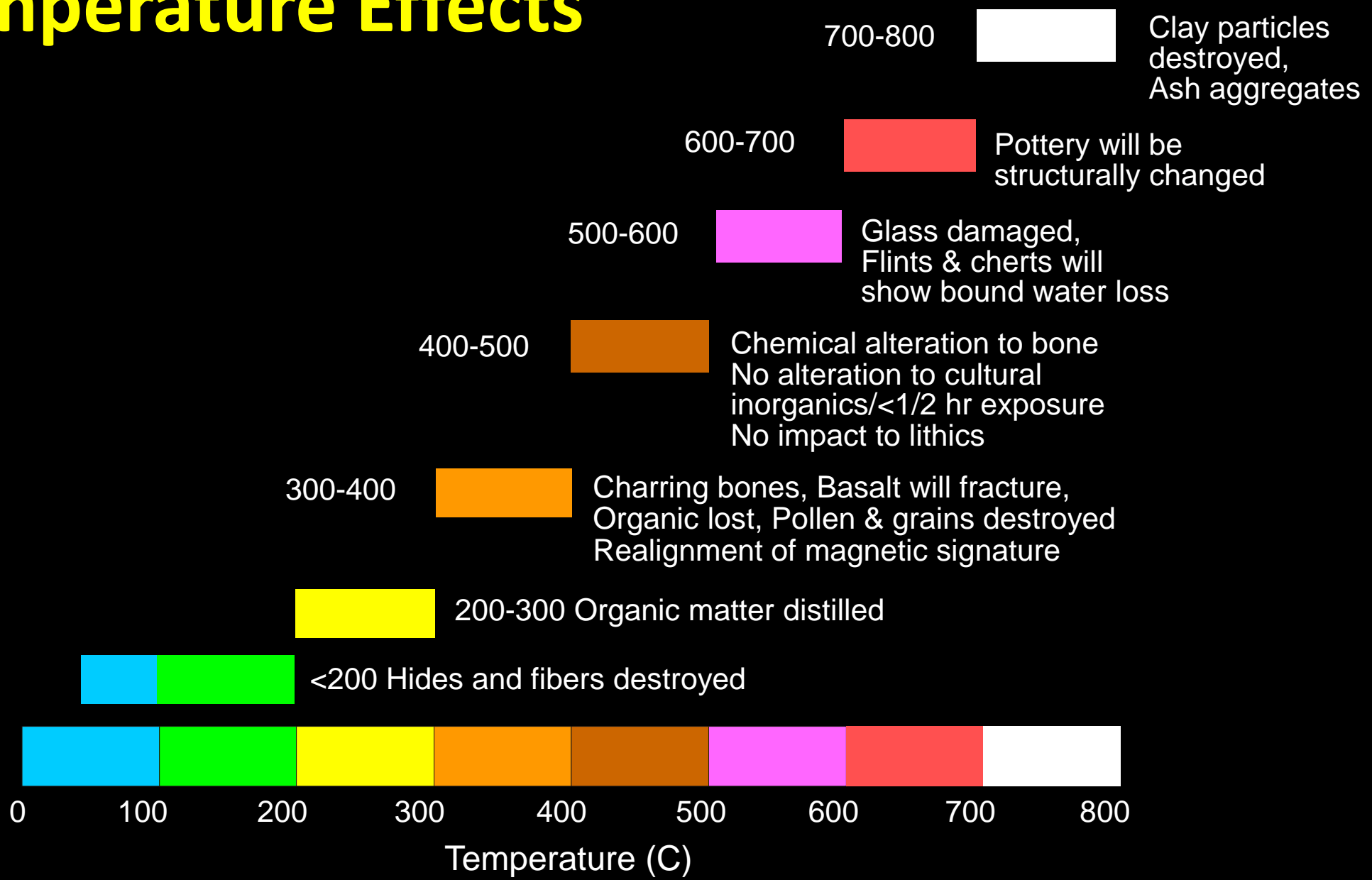
Crown Fire, No Duff Consumption



Crown Fire, Total Duff Consumption

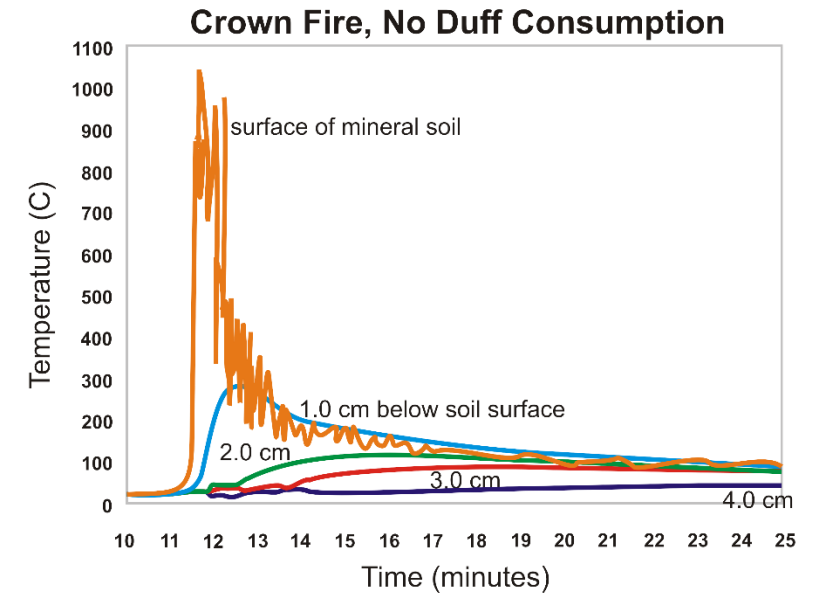
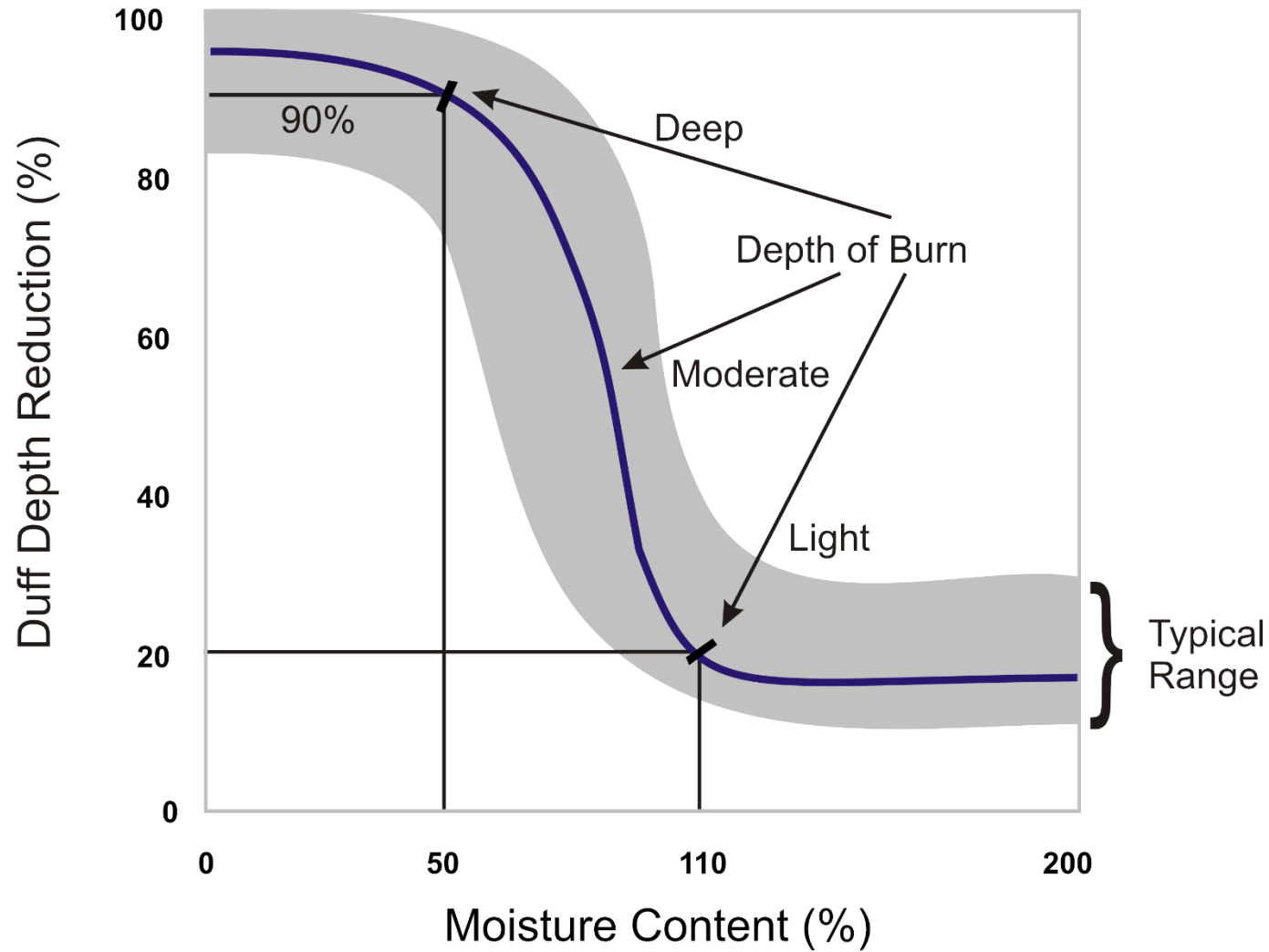


# Temperature Effects



# Fire effects - Depth of burn

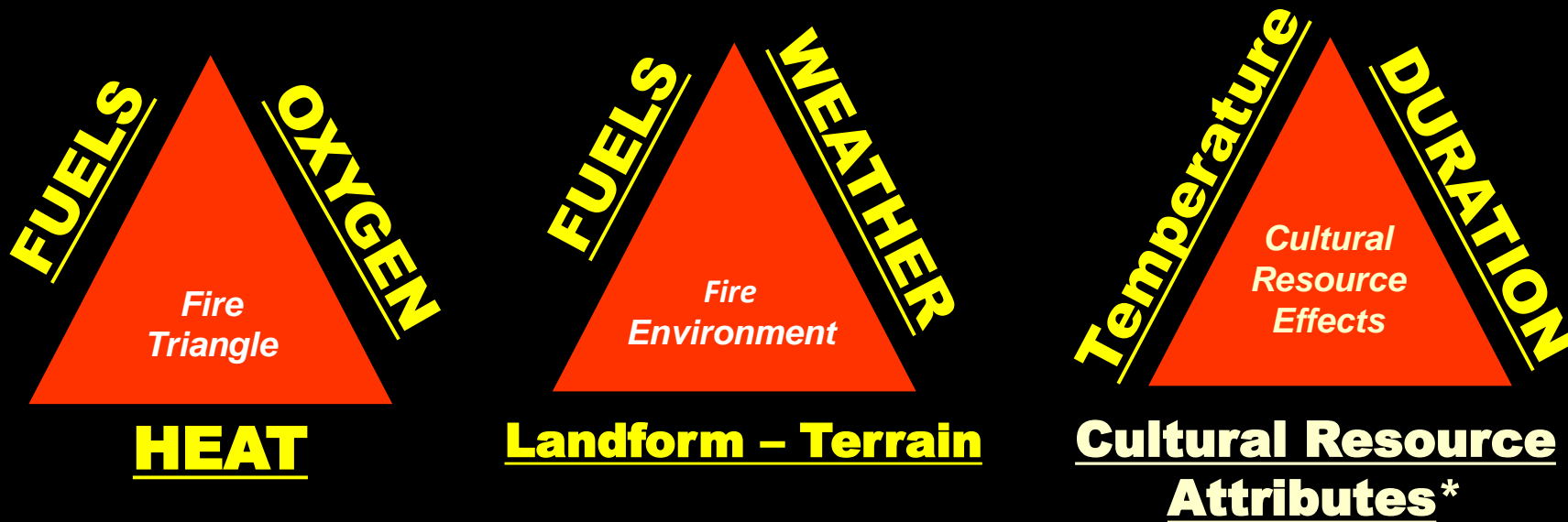
For Duff  $\geq 4$  cm Deep





# Easiest way to protect resources: Control the **heat pulse** and Reduce **fire residence** times

(manipulating fuels, burning under particular weather conditions, altering ignition patterns around resources, etc.)



*Change any leg of any of the triangles, and the outcome (effect) changes*

(\* size, shape, material, location above or below ground, associated data, etc.)

# Fire: From fuels to fire effects

## Fire environment



**Terrain**

**Weather**

**Fuels**

- Size, shape
- Moisture content
- Quantity
- Spatial arrangement (vertical and horizontal)



## Fire behavior

- Depth of burn
- Residence time
- Temperature
- Combustion byproducts
- Oxidation, reduction

## Fire effects

