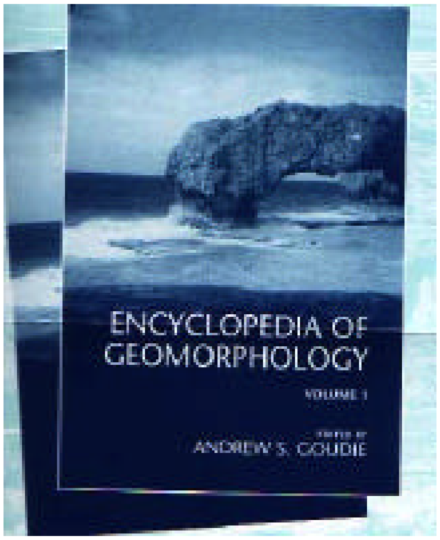

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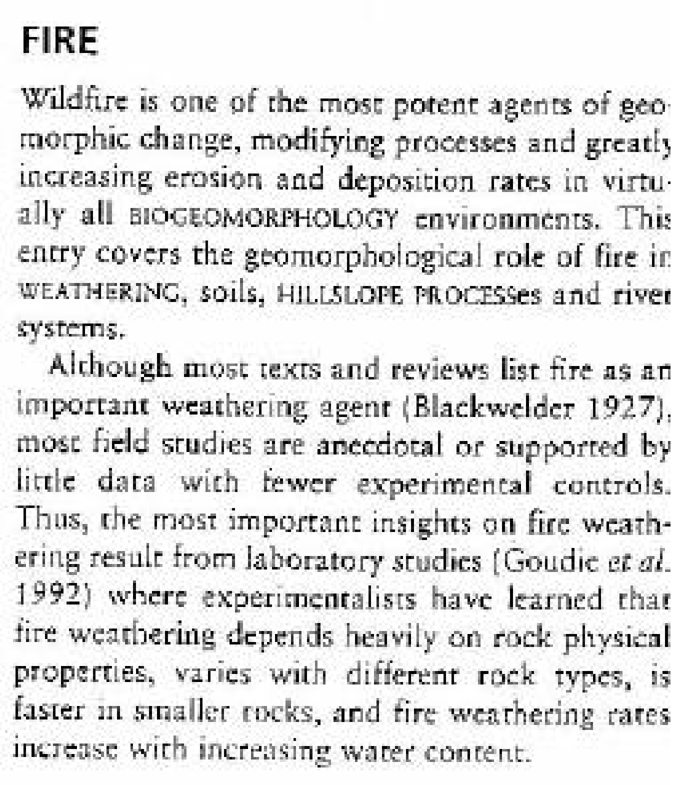

FIRE

Wildfire is one of the most potent agents of geomorphic change, modifying processes and greatly increasing erosion and deposition rates in virtually all BIOGEOMORPHOLOGY environments. This entry covers the geomorphological role of fire in WEATHERING, soils, HILLSLOPE PROCESSes and river systems.

Although most texts and reviews list fire as an important weathering agent (Blackwelder 1927), most field studies are anecdotal or supported by little data with fewer experimental controls. Thus, the most important insights on fire weathering result from laboratory studies (Goudie *et al.* 1992) where experimentalists have learned that fire weathering depends heavily on rock physical properties, varies with different rock types, is faster in smaller rocks, and fire weathering rates increase with increasing water content.

An example of the impact of fire on rock weathering comes from the April–May 2000 'Coon Creek' wildfire that burned around 37.5 km^2 of the Sierra Ancha Mountains, 32.3 km north of Globe, Arizona – including 25 sandstone and 19 diorite boulders surveyed in 1989 and resurveyed (a) after the burn, (b) after the summer 2000 precipitation season, and again (c) after the winter 2001 snow season (Dorn 2003, Plate 48). When stretched over cumulative boulder areas, erosion immediately after this single fire averaged > 26 mm for sandstone and > 42 mm for diorite. But averages are misleading, because sandstone and diorite boulders expressed bimodal patterns of erosion, where fire-induced weathering generated either (a) no

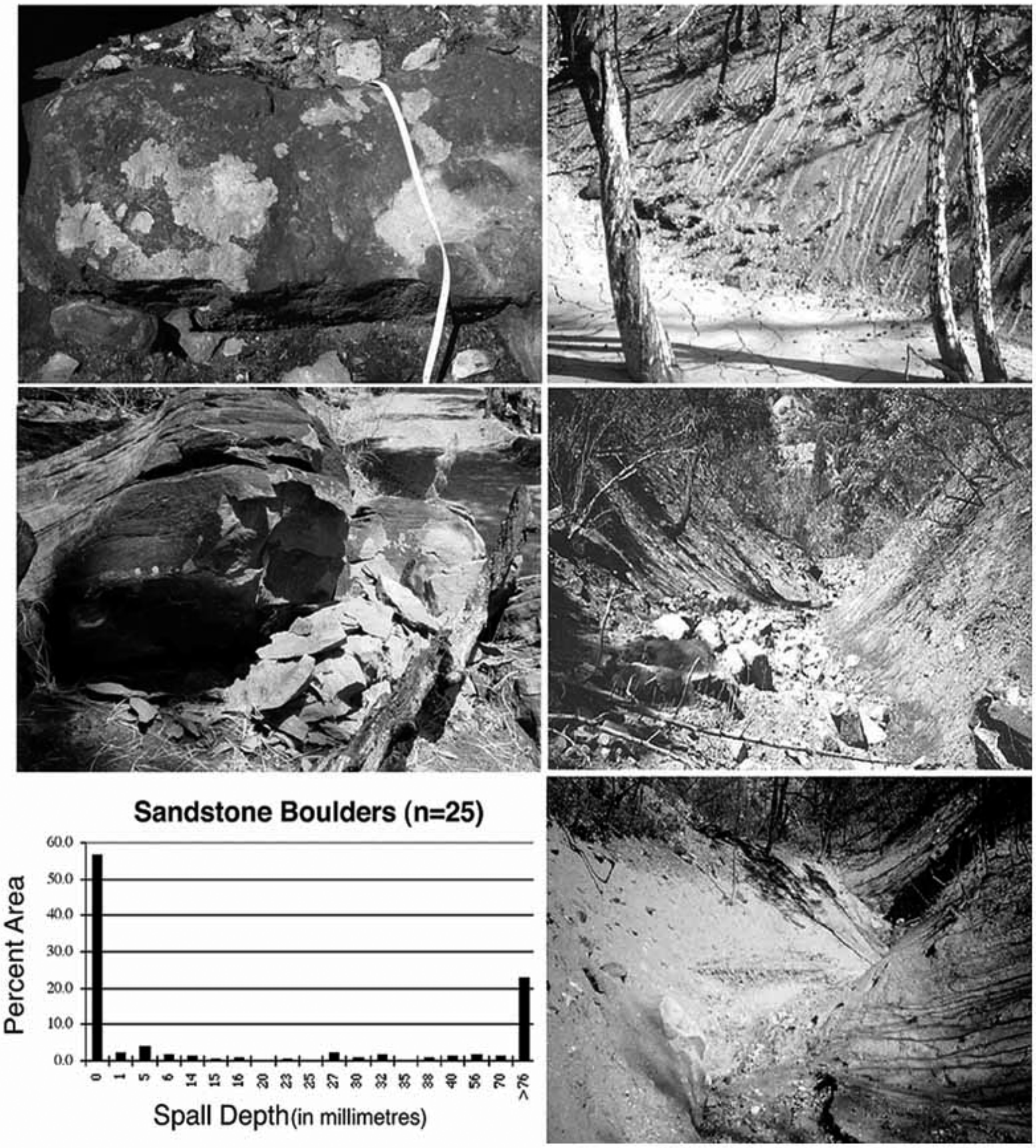

Plate 48 Left column: boulder weathering from the Coon Creek Spring 2000 fire, Sierra Ancha Mountains, Arizona. The top left image shows flaking of millimetre-scale spalls. The centre-left image shows where half of a boulder fragmented as a result of the fire. The graph on the lower left shows the overall bimodal pattern, whereby fire weathering produces erosion of small flakes or extensive slabs. Right column: fire-generated erosion from the 1995 Storm King fire, Colorado, courtesy of the US Geological Survey (Canon *et al.* 2001; see also http://landslides.usgs.gov/html_files/ofr95-508/index.html). The upper right image shows post-fire rill erosion. Other photos show in-channel conditions before (middle right) and after (lower right) passage of a debris flow

erosion to thin, millimetre-scale spalling or (b) massive spalls thicker than 7.6 cm. This field study confirms an earlier experimental finding that fire increases a rock's susceptibility to post-fire weathering and erosion processes (Goudie *et al.* 1992), since summer-time convective storms and subsequent winter snows continued to promote boulder erosion on the order of 1–5 millimetres. In addition to erosion of boulder surfaces, 85-metre- diameter boulders appear to have been fragmented into cm-scale clasts – suggesting that fire can modify hillslope evolution in locations where boulders are important controls on the evolution of slopes.

Wildfire generates extensive changes to soil systems (Morris and Moses 1987), perhaps the most important being the development of HYDROPHOBIC SOILS. Wildfires produce volatile hydrocarbons that penetrate soil up to 15 centimetres and make a water-repellent layer. In addition, fire ash decreases the ability of soils to adsorb water. Field checks involve digging a progressively deeper trench and applying water. Water that does not infiltrate immediately (within 10 seconds) indicates the soil is hydrophobic. Extreme hydrophobicity results in water ponding for more than 30 seconds. On unburned slopes, normal biogeomorphology processes decrease soil erosion, for example, by intercepting raindrop impacts, increasing infiltration and providing structural support. Hydrophobicity from burning decreases infiltration capacity, and increases OVERLAND FLOW and SOIL EROSION.

Even before it rains, burning enhances erosion by dust DEFLATION and dry ravel. Dry ravel is a type of granular MASS MOVEMENT where frictional and collisional particle interactions dominate flow behaviour, all not requiring rainfall. Dry ravel provides sediment to channels from particularly steep slopes, and this process is well documented after southern California fires.

Burning greatly increases surface runoff from precipitation, which increases the volume and velocity of the surface runoff. Higher discharge of surface water flows then result in the formation of RILLS and gullies (see GULLY) on hillsides. Fire-enhanced gullies and rills transport surface runoff and sediment to stream channels. Peak flows in the channel tend to occur with less of a lag time than those observed in unburned watersheds. Flood peaks tend to be much higher and more capable of eroding sediment stored in channels, leading to channel incision.

The sediment load of the fluvial system also changes after a fire. Sediment from a number of different sources may be incorporated into flows progressing down a hillside or channel. Sediment-water flows on burned slopes change the concentration, size distribution and/or composition of the entrained sediment to the point where a change in measurable yield strength takes place; this change is called HYPERCONCENTRATED FLOW. In hyperconcentrated flows, particles are deposited as individual grains from suspension, and the remaining fluid continues to move.

Fires also greatly increase DEBRIS FLOWS (Cannon *et al.* 2001; Swanson 1981). In contrast to streamflow or hyperconcentrated flow, debris flows host a sediment-water mixture that moves as a single phase. Deposition does not separate out particles, so debris-flow deposits have sharp, well-defined flow boundaries. The most recognizable deposits are levees lining flow paths and lobes of material at a flow terminus. Many terms have been used for the processes and deposits of debris flows, including slurry flow, mudflow and debris torrent.

Fire-enhanced debris flows start by landsliding or sediment bulking of surface water flows. Landsliding after burning tends to be more common in colluvial-filled hollows on slopes, where unconsolidated thick deposits of colluvium fail after rainfall. This landslide then mobilizes into a debris flow, where the debris-flow path can then be traced up to a landslide-scar source.

Sediment bulking tends to occur in the surface layer of hydrophobic soils. Hydrophobic soils create a condition where excess water that cannot penetrate deeply saturates the upper few centimetres of soil. This surface material then fails as small-scale debris flows. In addition, water runoff can incorporate so much loose material that sediment concentrations get high enough for the flow to behave as a debris flow. Sediment bulking is probably the most important debris-flow producing process after a fire.

GEOMORPHOLOGICAL HAZARDS are not limited to the first few rainstorms after a fire. Research by Ramon Arrowsmith in the Phoenix, Arizona, region indicates enhanced flash flooding potential decades after a brush fire. Even in forested regions, the supply of loosened material continues to deliver dry ravel sediment, hyperconcentrated flows and debris flows to stream systems for years after a fire.

The link between wildfire and increased erosion leading to large sedimentation events was made as early as 1949 by P.B. Rowe and colleagues working in southern California. They developed the concept of a 'fire–flood sequence' that has been studied extensively in a wide variety of river settings including alpine forests such as Yellowstone (Minshall *et al.* 1998), Mediterranean scrub (Shakesby *et al.* 1993) and even desert ranges (Germanoski and Miller 1995). In Yellowstone, for example, Minshall *et al.* (1998) found extensive RILL development, GULLY formation and MASS MOVEMENTS in burned watersheds during the summer of 1989, when post-fire heavy rains and snowmelt generated widespread 'black water' conditions and increased BEDLOAD and SUSPENDED LOAD. After monitoring Yellowstone streams for a decade after its massive wildfire, Minshall *et al.* (1998) stress that post-fire stream studies can yield misleading insights after only a few years since massive stream reorganization can take place seven to nine years after the fire event.

The study of fire remains associated with soils and sediment, called pedoanthrocology, provides important insight into prehistoric geomorphic changes associated with fires. Studies of fire-induced ALLUVIAL FANS, of fire remains within uneroded soils, and diagenesis of organic remains into such forms as vitrinite and inertinite provide geomorphologists with insights into palaeoecological conditions that may have influenced the geomorphic landscape seen today (Siffedine *et al.* 1994).

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