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Whitechuck Glacier, Glacier Peak Wilderness, Washington

A ruptured green balloon lies among ice worms, slowly photodegrading on the Whitechuck Glacier, on the slopes south of Glacier Peak in Washington's North Cascades. Ice worms inhabit glaciers (and only glaciers) in the coastal ranges from southern Alaska to Oregon, feeding on cold-tolerant algae and bacteria that also make snow and ice their home. The glacier has retreated rapidly in the last century, and is likely do disappear entirely in our own—ice worms, adapted to life on the glacier surface, will disappear with it.

The balloon, carelessly set free and fallen as litter, will never quite vanish; broken down by weathering, it will be eternalized as small, mobile fragments poisoning the soil, water and food chain.

Twisp Pass, North Cascades National Park, Washington

A shaft of light illuminates a dying lodgepole and whitebark pine forest decimated by a bark beetle outbreak near Twisp Pass, in Washington's North Cascades. Native bark beetle populations have exploded and caused unprecedented tree death throughout western North America since the late 1990s, turning once green valleys to rusty and grayish hues. Swarms of bark beetles ultimately suffocate their hosts by boring into, and feeding upon, the nutrient-conducting tissues under the bark, and introducing fungal and bacterial infections that they themselves carry. Humanity has been an unwitting partner to the beetles' present advance: fire suppression and other forest management practices have resulted in older, denser, and more homogeneous forests—prime beetle fodder—and a warming climate has greatly enhanced the beetles' ability to reproduce and eat their way across the landscape, allowing them to move up in latitude (e.g. Canada's boreal forests) and altitude (e.g. Washington's whitebark pine), and to survive winters that would have otherwise killed their larvae.

Painted Hills Unit, John Day Fossil Beds National Monument, Oregon

Roughly 40 million years of earth history is exposed in Oregon's Painted Hills. Cream-colored ash, spewed from distant and nearby volcanic eruptions, formed the bulk of the John Day Formation. As the volcanic ash weathered, the mineral deposits oxidized, colors accumulating in alternating layers of lake-bed sediments and soils. The black is lignite, soil rich in plant matter; the grays are mudstones and shales, sedimentary rocks formed from ancient lake bottoms; the reds are the iron oxides of laterite soils, soils that typically form under hot and humid conditions. Evidently, this land has not always been desert. Buried in the volcanic ash is a fossil record that richly illustrates the area as a forest of palms and tree ferns, and reveals a transition to a temperate hardwood forest—grazed by oreodonts, tapirs and early horses—as the climate dried and cooled.

On the Pacific Coast near the village of Mazunte, Oaxaca State, Mexico

These unusual sandstone formations have been polished, pitted and grooved by salt from the Pacific Ocean, sprayed down upon them relentlessly by wind and surf. As the deposited saltwater evaporates, the salt forms crystals both on the surface of the rock, and within the tiny pore spaces between the rock grains, prying them apart and wreaking tiny havoc on the structural integrity of the rock. Since more salt-bearing water is captured in existing depressions, the deepening of a hole encourages yet further erosion. The resulting honeycomb structures have earned this common type of coastal salt weathering the nickname "alveolar weathering," after their resemblance to the alveoli of the lungs.

On the trail to Everest Base Camp, Himalaya Mountains, Nepal

Pumori (7161m) looms over piles of unconsolidated glacial debris, or moraines, at the confluence of the Changri Shar and Khumbu Glaciers. Glaciers, like giant conveyor belts, transport rock and soil downvalley, both by plowing the valley walls and floor as they advance and by carrying debris that has fallen onto their surface. The debris contained on and in the ice eventually reaches the snout of the glacier, where it is dumped in big heaps as the surrounding ice melts away.

Emerging landscape at Columbia Glacier, Alaska

As the Columbia, a large tidewater glacier near Valdez, Alaska, contracts rapidly from melt and—much more significantly—from the regular calving of icebergs, rocks and soil once riding in and on the glacier are deposited erratically across the emerging landscape. The grooves and gouges etched into the polished bedrock are testimony of the last glacial advance not so long ago.

By carbon dating dead snags killed and plowed over when the glacier was last advancing down its ocean fjord, scientists have been able to reconstruct the glacier's most recent schedule. The glacier took several centuries to reach, by around 1440 AD, the terminus position it steadily occupied until the early 1980s. The retreat, as observers have discovered, can be far quicker. Already the Columbia Glacier has lost 18 of its original 66 km, and thinned by over 400 meters—a lost volume of ice estimated as high as 140 km^3.

View of the Picket Range from Luna Peak, North Cascades National Park, Washington

The Western U.S. was violently assembled through repeated collisions between drifting rock masses and the North American continent, forming jumbles of mountains which in time eroded away. In the last 40 million years, the subduction of heavier oceanic crust pushed the North Cascades upwards once again, exposing in peaks and ridges the metamorphic rock formed in the intense heat and pressure of the ancient collisions.

The Pickets are carved from this hard crystalline backbone. Once a more continuous ridge, the subrange has been scalloped by alpine glaciers and deeply dissected by now-departed valley glaciers. But resistant to erosion, they persist as the steepest peaks.

The North Cascades are among the youngest and most rugged mountains in the world, but wind, water and especially ice (in fact, most of the glaciers in the Lower 48—roughly 700) will eventually level the peaks, returning them once again to the sea.

Coastal salt flats near Laguna San Ignacio, Baja California Sur, Mexico

Coastal salt flats form in shallow coastal basins flooded by large tidal rhythms. Where the climate is sufficiently dry, the flooded basins evaporate and high salinities develop in the substrate.

Laguna San Ignacio, adjacent to these salt flats, is the last undeveloped gray whale birthing area on the planet. In 2000, caving to public pressure to protect the whale nursery, the Mexican government cancelled a joint venture with Mitsubishi subsidiary ESSA (Exportadora de Sal, S.A) that would have established the largest industrial salt evaporation facility in the world. It was projected to produce seven million tons of salt a year over 116 square miles.

Dry wash in the Mancos Shale badlands near Caineville, Utah

Dessication mudcracks form in moist, fine-grained sediment (mud, for instance) that is periodically exposed to the air. The cracks, which create a polygonal pattern at the surface, taper into a "V" as they penetrate (up to several inches) into the ground. The cracks usually fill with stray sediment different from the base material before burial and petrification, so mudcrack patterns are often encountered fossilized in the geologic record. Most useful indeed: they indicate that the layer of rock formed in a wet but air-dried environment—perhaps an intertidal zone, or a dry wash—and they point out which way was up, as the points of their "V"s always form pointing down.

Frost-rimmed rock shards near Caineville, Utah

The daily freeze-thaw cycle of water, typical of extreme desert climates, can efficiently split apart rock by the process of frost wedging. Rocks naturally contain small cracks, or joints, into which rainwater eventually seeps. As days turn to night, the water in the joints freezes and expands, widening the joints ever slightly. As nights turn back into day, more liquid water descends into the enlarged joints to form yet more ice each consecutive night. Eventually, the joints reach all the way through, splitting the rock.

Sea stacks at Shi Shi Beach, Olympic National Park, Washington

A single cubic meter of water weighs one ton. Massive stuff. When storm waves pound the coast, they do so with terrific force, hurling against the rocks their own enormous weight and any sand, boulders and driftwood they have entrained. As the mechanical forces grind the surface, the high pressures force seawater into tiny fissures, enhancing the weathering process.

The waves are powered by the offshore winds that brush the water's surface, themselves powered by the rotation of the earth beneath the atmosphere, and the differential heating of the equator and the poles by the sun. Ultimately, celestial energy drives the erosion of shuddering coastlines.

Much of this energy runs aground on protruding headlands, both at the far tip and along the sides as the waves bend to the coastline. Erosion of the side walls eventually leads to sea arches, and when those collapse, sea stacks—the signature formations of Washington's Olympic Coast.

Copper Canyon (Barrancas del Cobre) and the town of Urique, Chihuahua State, Mexico

Barrancas del Cobre is in fact an elaborate network of six interconnected canyons. The deepest of these, Urique Canyon, is also the deepest in North America: 1,870 meters, nearly 300 meters deeper than the Grand Canyon. But unlike the Grand Canyon, which exposes two billion years of geologic history in its colorful strata, the Copper Canyons are cut through rock of relatively uniform age.

The strata were laid down quickly. Around 25 million years ago, massive intrusions of magma reached the surface, seeping out through vents and fissures in the Earth's crust—and more violently as pyroclastic flows, hot avalanches of gas and rock that traveled over the surrounding landscape at speeds as great as 700 km/h following explosive volcanic eruptions. Rivers draining this new plateau, finding an ocean outlet far below, began downcutting through the fresh substrate and created the canyon system that exists today.

Between the highlands and the canyon depths, the region hosts a remarkable range of ecosystems and climates. In a single autumn day, the photographer set off from the rim, through pine and oak forests shrouded in snow and mist, to arrive in the town of Urique by afternoon under clear hot skies and fruiting Guava trees. For the indigenous Tarahumara Indians, "land below" and "hot land" are synonymous, and captured in the word "Uli-qui", inspiring the name "Urique" when the town was founded by the Spanish in 1690.

Jumbo Rocks, Joshua Tree National Park, California

The famous boulders of Joshua Tree were not piled up from the ground up. They were simply left behind as an ancient landscape was washed away.

The story begins over 100 million years ago, when magma rose from the hot interior, oozing into open spaces and pushing the local ("country") rock aside. The magma slowly cooled and solidified as giant masses of hard granite far below the Earth's surface. Later, as erosion removed the overlying surface rock, the granite masses rebounded, developing a system of horizontal fractures as they expanded upwards, and vertical fractures, parallel to the boundary with the surrounding rock, as they expanded outwards.

With much of the overlying rock removed, ground water began to reach down into the fractures, dissolving hard minerals into soft clay and plucking off granite crystals resistant to solution. The hardest blocks persisted, but their sharp corners, most exposed to the erosive forces of the water, were the first to go. Rectangular blocks became spheres, the spaces between them filled only with soft clays and loose grains.

The surviving granite remained buried underground until flash foods eventually removed the last of the protective surface. As the loose debris washed away, the huge rounded boulders were exposed one by one and left high and dry in the giant piles climbers celebrate today.

West branch of the Columbia Glacier, Alaska

The Columbia Glacier, which twists down from Alaska's Chugach Mountains into Prince William Sound, is one of the fastest disappearing acts in the world, having lost 18 of its original 66 kilometers and deflated by over 400 meters since the early 1980s.

Much of the main branch lies barely above sea level, making it particularly sensitive to changes in climate. As it melted (due to increased summer melt, decreased winter accumulation, or some combination thereof), it became thin enough to lift off the bottom of its fjord. Heated and lubricated from below while relentlessly urged forward by the weight of ice upstream, it now plunges into the ocean (at an average 15-20 meters per day), calving off huge icebergs into the Sound.

The west branch is now functionally a separate glacier, as the main branch has receded past the confluence. Unlike the main branch, which is still floating and highly unstable at its current terminus, the west branch is now completely grounded and therefore much less active.

Indian Tunnel lava tube, Craters of the Moon National Monument, Idaho

Lava tubes form as the cooling exterior of an active lava flow hardens into a hard crust, insulating the molten river within. When the flow ceases, a tubular cave remains: Indian Tunnel is 240 meters long, 10 meters tall and 15 meters wide.

The Craters of the Moon Lava Field was born of the same hotspot that now, 10 million years later, sits under Yellowstone National Park (due to the southwestward movement of the North American plate over the stationary hotspot). When later rifts formed from stretching of the crust, it was leftover heat from this hot spot that oozed out of the fissures to form the lava flows at Craters of the Moon some 2 to 15 thousand years ago. Considered only dormant, the fissures are expected to erupt again in the next thousand years...

Rocky shore of Pescadero State Beach, California

A long exposure blurs the waves of the Pacific Ocean as they ride up onto a boulder-strewn beach. At Pescadero, the boulders are born by "wave quarrying" of the bedrock directly above. Once freed, these large chunks begin their stubborn descent to the sea, too heavy to be pushed back by anything but the largest storm waves. Due to the constant abrasion of gravel and sand grains sent tumbling by the surf, the boulders become ever more rounded and polished as they reach the base of the beach.

Dunes of Erg Zehar, two days by camel from M'Hamid, Morocco

As wind brushes over sand, it plucks off grains exposed by even the slightest surface roughness. But the grains quickly drop back to the ground—they are, after all, two thousand times denser than the atmosphere. How then is wind capable of transporting great quantities of sand over long distances?

If a grain falls onto a hard surface, it will bounce back into the air. If it lands on a sandy surface, it will relay its energy and eject a new grain into the air. In either case, the wind will once again provide forward momentum to the airborne grain. This process is known as saltation, and accounts for 75% of sand transport by wind. When a saltating grain impacts a larger grain too heavy to be ejected, the energy imparted will nevertheless move the particle downwind slightly—a mechanism, known as surface creep, that accounts for the remaining 25% of sand transport by wind.

Consider now a small hollow in otherwise flat sand (a mental image will help). Saltating grains strike the downwind slope of the hollow more often than they do the upwind slope, since the latter is sheltered from the wind. This results in considerably more surface creep up the downwind slope than down the upwind slope, deepening the hollow and creating a new ripple above it. This ripple becomes the upwind slope of yet a new hollow, and the process repeats itself, forming a repeating series of parallel ridges perpendicular to the wind direction.

Factory Butte at sunrise, near Caineville, Utah

These cliffs are made of gray Mancos Shale, poorly solidified sedimentary rock laid down in the Cretaceous period (145-65 million years ago) at a time when a great inland seaway split North America through the middle. Eroding mountains and active volcanoes to the west delivered vast amounts of mud and silt to the inland sea, sediment which in time accumulated to a thickness of hundreds of meters. Clams, snails and oysters, fish and sharks, ammonites and giant sea-going lizards, all left behind fossils in this ancient ocean bottom.

The loose cliffs of Factory Butte owe their proud, persisting existence to the protective cap of Emery Sandstone—much more competent rock laid down by a later surge of sediment from the west.

Quartz veins, Shi Shi Beach, Olympic National Park, Washington

Mineral veins form very quickly by geologic standards. Hot water, rising from a geothermal heat source deep underground, forces its way towards the surface through fractures in the rock, precipitating minerals like silica (quartz) as it cools. The pressures are so high that these open channels, generally only millimeters or micrometers wide at any given time, cannot be maintained for long. Veins achieve greater thicknesses by the progressive reopening of the fracture and deposition of minerals on the growth surface.

Aerial view of fluvial network in the sagebrush steppe of northern Arizona

Dendritic drainage patterns, reminiscent of the branches of a tree or the veins of the human circulatory system, occur most commonly where the underlying rock or sediment is flat and homogeneous. In the absence of existing fissures to guide flow, water erodes channels that, although initially random, unavoidably converge into increasingly wider and deeper troughs. This erosion pattern conserves energy since deeper troughs minimize the friction between the water and the the channel bottom.

Water-filled pothole near Caineville, Utah

Potholes, a common sight in southern Utah, typically form on flat sandstone surfaces. Rainwater collects in natural depressions and fractures, deepening of the hole encouraging further weathering by wind and water.

This geochemical process is aided, in part, by geobiologic processes. The photosynthesis of cryptoendolithic ("hidden within rock") algae, which live in the tiny spaces between the sand grains, creates a basic pH environment that promotes the dissolving of silica, the cement that binds the sand grains together. Though safe from most fish and insect predators, the unique assemblages of organisms that colonize potholes must be able to sustain periodic drying of the pool, and the extreme swings in temperature, pH and gas concentrations that result.

Mancos Shale badlands near Caineville, Utah

University of Colorado professor Robert Anderson leads students through the rounded slopes of the Mancos Shale badlands near Caineville, Utah. Below the smooth surface crust is unweathered shale, itself poorly solidified sedimentary rock laid down in the Cretaceous period (145-65 million years ago) at a time when a great inland seaway split North America through the middle.

One of the lessons Anderson imparts to his students is an explanation for why most hills are round. This striking generality was described in 1909 by Grove Karl Gilbert, an American geologist who first studied the area, and whom Anderson venerates as a founding father of geomorphology.

Imagine a hill in cross-section, labeled with points "D" at the summit, "A" half-way down the slope, and "B" at the bottom. While the bulk of the hill is bedrock, it is topped by a thin layer of loose material, called regolith, that is released continuously through weathering. For the hill to shed new regolith, the regolith produced between points D and A must eventually creep past A, while both the regolith produced between points D and A and points A and B must eventually creep past B. If the erosional process is proportional to the grade, as it most usually is, then it follows that the hill must be twice as steep at B than it is at A ... Admittedly a circular, but hopefully enlightening, formulation for why hills maintain a rounded figure as they erode.

Second Beach, Olympic National Park, Washington

A wave slides past a grey pebble set against an unusual pattern in the sand. University of Colorado geomorphology professor Robert Anderson explains that the pattern is associated with slight steering of the backwash as it flows down the beach face, liquefying sand in little flat-floored channels.

Abyss Pool, West Thumb Geyser Basin, Yellowstone National Park, Wyoming

The geothermal features of Yellowstone National Park are fueled by the heat of an underlying hotspot, a bulge or plume in the Earth's mantle bringing molten rock close to the surface. Over the last 15 million years, this stationary hotspot has caused large scale volcanism across Oregon, Nevada, Idaho, and Wyoming as the North American plate continues to slide over it.

The West Thumb Geyser Basin was created by a violent eruption about 150,000 years ago—the emptied magma chamber collapsed, forming a large cauldron-like depression known as a caldera. Abyss Pool, at 16 meters one of the deepest hot springs in the park, is heated to 82°C by a geothermal heat source believed to lie only three kilometers below the surface. The bright colors lining the edge are the photosynthetic pigments of thermophilic ("heat-loving") bacteria, organized in bands of color according to their preferred temperature.