

= Geology of the Lassen volcanic area =

The geology of the Lassen volcanic area presents a record of sedimentation and volcanic activity in the area in and around Lassen Volcanic National Park in Northern California , U.S. The park is located in the southernmost part of the Cascade Mountain Range in the Pacific Northwest region of the United States . Pacific Oceanic tectonic plates have plunged below the North American Plate in this part of North America for hundreds of millions of years . Heat from these subducting plates has fed scores of volcanoes in California , Oregon , Washington and British Columbia over at least the past 30 million years ( see Geology of the Pacific Northwest ) and is also responsible for activities in the Lassen volcanic area .

Between 3 and 4 million years ago , volcanic @-@ derived mud flows called lahars streamed down several major mountains that included nearby but now extinct Mount Yana and Mount Maidu to become the Tuscan Formation . Basaltic and later andesitic to dacitic flows of lava covered increasingly larger areas of this formation to eventually form the lava plateau that the park sits on . About 600 @,@ 000 years ago , Mount Tehama started to rise as a stratovolcano in the southwestern corner of the park , eventually reaching an estimated 11 @,@ 000 ft ( 3 @,@ 400 m ) in height . Following a series of eruptions approximately 350 @,@ 000 years ago , its cone collapsed into itself to form a 2 mi ( 3 @.@ 2 km ) wide caldera .

Roughly 27 @,@ 000 years ago , a dacite lava dome quickly pushed its way through Tehama 's destroyed north @-@ eastern flank , becoming the approximately 1 @,@ 000 ft ( 300 m ) shorter Lassen Peak . Lassen 's shape was significantly altered by glacial erosion from 25 @,@ 000 to 18 @,@ 000 years ago during the Wisconsin glaciation . Since then , smaller dacite domes such as the 1 @,@ 100 @-@ year @-@ old Chaos Crags have formed around Lassen . Phreatic ( steam explosion ) eruptions , dacite and andesite lava flows along with cinder cone formation have persisted into modern times . Most notable of these is the mid to late 17th century eruption and formation ( Tree Ring dates ) of Cinder Cone and the early 20th century eruption of Lassen Peak . The only activity since then has been the constant bubbling of mud pots and steaming of fumaroles from the various geothermal areas in Lassen Volcanic National Park . However , a potential exists for renewed vigorous volcanic activity that could threaten life and property in the area .

= = Regional geologic setting = =

= = = Current setting = = =

The Lassen volcanic area lies at the southern extremity of the Cascade Range , which extends northward some 500 mi ( 800 km ) from Lassen Peak within the park through Oregon and Washington and into British Columbia . Lassen Peak and the 16 other major Cascade Volcanoes form a segment of a ring of volcanoes that circle the Pacific Ocean known collectively as the ' Pacific Ring of Fire . ' The Cascade Volcanoes are fed by heat generated as the Gorda and Juan de Fuca tectonic plates are being subducted below the much larger but lighter North American Plate . Lying some 300 mi ( 480 km ) offshore , the spreading center of the Gorda Plate pushes out about 1 in ( 2 @.@ 54 cm ) of new crust toward the coast of Northernmost California and southern Oregon every year .

The composition of the molten rock ( magma ) that feeds volcanism in the Lassen volcanic area ranges widely in its content of silica or SiO

2 ; the higher the silica content , the greater the ability of the magma to trap and hold on to gas and water vapor . When high @-@ silica ( dacitic ) magma rises to the Earth 's surface , the trapped gases and vapors can erupt explosively to produce ash clouds and pyroclastic flows that consist of superheated gas , ash and volcanic fragments . Dacite magma that is extruded nonexplosively as lava forms lava domes because it is too viscous ( sticky ) to flow far away from its source . Low @-@ silica ( basaltic ) magma is more fluid and usually erupts as lava in less explosive eruptions than dacite because gas and water vapor escape easily from it . Eruptions of basalt magma typically

produce elongate lava flows , as well as build cinder cones ( piles of small frothy lava fragments or ' cinders ' ) around volcanic vents .

Basaltic volcanism in the Lassen volcanic area occurs mainly along chains of vents aligned in a north or northwest direction , parallel to regional faults . Examples include Poison Buttes , Subglacial Buttes , Tumble Buttes , the Prospect Peak @-@ Red Cinder area , the east side of the Hat Creek Valley and Potato Buttes @-@ Sugarloaf area , and the Red Lake Mountain area . Prolonged basaltic volcanism at a single site can produce a sizeable edifice , like the broad , relatively flat shield volcanoes of Prospect Peak and Sifford Mountain .

Northwest of the park lies the Klamath Mountains ( a collective term for the Siskiyou , Trinity , Salmon and Marble mountain ranges ) . To the west lies the Sacramento Valley . Just south of the park begins the Sierra Nevada , and to the east lie the Modoc Plateau and then the Great Basin .

= = = Geologic history of the region = = =

All rock now exposed in the area of the park is volcanic , but this has not always been the case . For hundreds of millions of years , the Lassen region underwent repeated uplifting to form mountains , only to have them worn down and submerged under encroaching seas . During the periods of submersion , sand , mud and limestone were deposited . Occasionally volcanic activity was associated with the mountain building .

About 70 million years ago , the area where the Cascade Range is now situated was under the most recent encroachment by the Pacific Ocean . The rocks that make up the modern Sierra Nevada and the Klamath Mountains were already in existence but deeply buried . Some 70 million years before ( 140 million years before present ) , the rocks that now make up the Klamaths broke away from the rocks that now make up the Sierras and moved 60 mi ( 97 km ) west , leaving the flooded ' Lassen Strait . ' This broad depression was a seaway that connected the marine basin in California with that in east central Oregon .

The entire western portion of North America was being deformed from the Laramide orogeny starting around 70 million years ago . Gradually during millions of years , crustal rocks were folded and fractured and the seas driven away . This same bending and breaking of rocks relieved pressure on the hot material beneath the Earth 's crust and permitted magma to rise toward the surface . Volcanoes burst into activity starting 30 million years ago from Washington southward along the Cascades and in the area now occupied by the Sierra Nevada . This activity continued until approximately 11 or 12 million years ago . Lava and ash reached a thickness of up to 10 @,@ 000 ft ( 3 @,@ 000 m ) in some areas , forming what is now known as the western Cascades . These have been eroded until they are now rolling hills .

Meanwhile , toward the end of this activity , eruptions of a different kind took place on an unprecedented scale in eastern Oregon and Washington . From innumerable cracks , floods of highly fluid basaltic lava spread to cover an area of over 200 @,@ 000 sq mi ( 520 @,@ 000 km<sup>2</sup> ) . Now known as the Columbia Plateau , this great lava bed of flood basalt covers much of Oregon , Washington and even parts of Idaho . Northern California 's Modoc Plateau is a thinner basaltic flow which some geologists associate with the Columbia Plateau , but there are technical objections to this . The High Cascades took shape as a distinct mountain belt as a result of this upheaval and the bending of the thick blanket of volcanic rocks . During the next 10 million years , a series of new basaltic volcanic cones similar to the shield volcanoes now found in Hawaii were built .

= = Formation of basement rocks = =

Between two and three million years ago , during the Pliocene , the Sierra Nevada was uplifted and tilted westward . A series of volcanic mudflows ( lahars ) from three major source areas contributed debris that covered almost 2 @,@ 000 sq mi ( 5 @,@ 200 km<sup>2</sup> ) to form the oldest distinctive geologic formation in the High Cascades . The resulting Tuscan Formation is not exposed anywhere in the national park but it is just below the surface in many places within it . The oldest pyroclastic material in the formation is 3 or 4 million years old . The youngest part of the formation consists of

interbedded conglomerates and volcanic breccias that are 2 million years old .

One major source of the formation was Mount Yana ; centered a few miles ( 5 km ) southwest of Butt Mountain and south of the park . Mount Yana had probably reached its full size of 10 @, @ 000 ft ( 3 @, @ 000 m ) in elevation and 15 mi ( 24 km ) in diameter before Mount Maidu , the second source , had acquired half its growth . Mount Maidu , which eventually surpassed Mount Yana in size , was centered over what is now the town of Mineral , California but has been extinct for hundreds of thousands of years ( the grassy plain around the town is Maidu 's caldera ) . A third source situated north of Latour Butte made a lesser contribution to the formation . Minor sources included an area near Hatchet Mountain Pass ( northwest of Burney Mountain ) , dikes south and southwest of Inskip Hill and possibly Campbell Mound ( north of Chico , California ) .

Meanwhile , within the park boundary other volcanic events were taking place . Basaltic lavas poured forth in the vicinity of Willow Lake in the southwestern portion of the park . These were followed by a very thick sequence of very fluid andesitic lavas which erupted near Juniper Lake and flowed westward about four miles ( 6 km ) . At about the same time , other andesitic lavas poured from several vents on the central plateau to cover an area of at least 30 sq mi ( 78 km<sup>2</sup> ) . Included among these flows were the Twin Lake lavas of black porphyritic andesite , which are notable in that they contain xenocrysts of quartz . The Flatiron andesites spread over the southwestern part of the park area around this time . Apparently , the vents of these lavas renewed activity at a much later date to form three cinder cones : Hat Mountain , Crater Butte and Fairfield Peak .

Somewhat later , andesitic lavas poured out from what is now Reading Peak and mainly flowed to the south and east , reaching the head of Warner Valley . By this time , the park 's eastern portion had been transformed into a relatively flat plain . The activity was followed by an eruption of the Eastern basalts from volcanoes east of the park . These thick flows have subsequently eroded to produce rugged hills that limit the park on the east . Taken together , these various flows built the lava plateau that the Lassen volcanic area is located on .

= = Volcanoes rise and fall in the park area = =

= = = Mount Tehama and pre @-@ Lassen volcanics = = =

From 600 @, @ 000 to 400 @, @ 000 years ago , eruptions built a large conical stratovolcano called Mount Tehama ( also called Brokeoff Volcano ) in what is now the southwest corner of the park . It was made of roughly alternating layers of andesitic lavas and tephra ( volcanic ash , breccia , and pumice ) with increasing amounts of tephra with elevation .

Tehama eventually reached an elevation of about 11 @, @ 000 ft ( 3 @, @ 400 m ) , was 11 to 15 miles ( 18 to 24 km ) wide at its base , and contained 80 km<sup>3</sup> ( 19 cu mi ) of material . Its principal vent lay in the neighborhood of what is now Sulphur Works , but a second vent from which no lavas issued lay on the eastern flank of Little Hot Springs Valley . Contrary to popular belief , Bumpass Hell is not one of Tehama 's main vents since it is located outside of the caldera .

It is possible that Tehama collapsed along a series of fault lines which criss @-@ crossed it . The trigger for this possible collapse may have been the release of the extensive amounts of lava that formed the dacite domes on its flank . More likely , the volcano weathered away ; hot volcanic gases and steam turned hard rock into soft clay that were easily eroded by glacial action . Either way , the largest remnants of Tehama include Brokeoff Mountain , Mount Conard , Mount Diller , and Pilot Pinnacle . Andesites erupted again in the area starting approximately 300 @, @ 000 years ago and dacite erupted in the area between 250 @, @ 000 and 200 @, @ 000 years ago and 100 @, @ 000 years ago through the present .

Four shield volcanoes ( Raker and Prospect Peaks , Sifford Mountain and Mount Harkness ) grew to elevations of between 7 @, @ 000 to 8 @, @ 400 ft ( 2 @, @ 100 to 2 @, @ 600 m ) at the corners of the central plateau . Raker Peak erupted andesite lavas while basalt flowed from the others . Each of these volcanoes developed a cinder cone on its summit during their last stages of eruption . Later , a mass of rhyolite was forced through the north flank of Sifford Mountain and a plug of dacite

was pushed up through the west flank of Raker Peak .

In the past 50 @, @ 000 years , at least seven major episodes of dacitic volcanism produced lava domes and pyroclastic deposits in the Lassen volcanic area , and another five episodes produced basaltic and andesitic ( silica content between basalt and dacite ) lava flows . Eruptions have occurred at sites including Lassen Peak , Chaos Crags , and Sunflower Flat ( explosive dacite eruptions followed by dome growth ) and Tumble Buttes , Hat Mountain , and Prospect Peak ( basalt eruptions ) . In addition , about 30 smaller volcanoes erupted basaltic lavas in the larger region surrounding the Lassen volcanic center .

= = = Development of Lassen Peak = = =

Radiometric dating indicates that around 31 @, @ 000 years ago a new vent opened up on the northeastern slope of Tehama , probably close to where Lassen Peak now stands . Streams of fluid dacite flowed chiefly toward the north , reaching a thickness of 1 @, @ 500 ft ( 460 m ) and covering perhaps 20 square miles ( 52 km<sup>2</sup> ) . Known as the Loomis Sequence , these pre @-@ Lassen dacites are the black , glassy , columnar lavas that now encircle Lassen Peak .

Sometime between 25 @, @ 000 and 31 @, @ 000 years ago , Lassen Peak , a Pelean lava dome volcano , was pushed up through the pre @-@ Lassen dacites . Lassen grew past the normal maximum size of plug dome volcanoes , 1 @, @ 000 ft ( 300 m ) , and reached a height of 1 @, @ 800 feet ( 550 m ) above the surrounding plateau in as little as a few years . The surface of the growing pile of about a 1 cu mi ( 4 @. @ 2 km<sup>3</sup> ) of lava crumbled continually , forming enormous banks of talus . When Lassen Peak formed it looked much like the nearby Chaos Crags domes do today , with steep sides covered by angular rock talus . Lassen Peak 's shape was significantly altered by glacial erosion from 25 @, @ 000 to 18 @, @ 000 years ago during the Wisconsin glaciation . At least one of Lassen 's glaciers extended as far as 7 mi ( 11 km ) from the volcano itself .

Later , but not precisely dated , eruptions from the Lassen volcanic area have formed over 30 smaller steep @-@ sided , mound @-@ shaped accumulations of volcanic rock , called lava domes . Crescent Crater , which at first glance appears as a parasite on Lassen 's northeast flank , has been more heavily glaciated and thus is older . Other dacite domes which rose on Tehama 's flanks are Bumpass Mountain , Helen Ridge , Eagle Peak , Vulcan 's Castle and Reading Peak . An upper limit of 10 @, @ 000 years has been set for the domes next to Lost Creek ( north domes ) . All of these domes must have risen with great rapidity .

= = = Glacial action = = =

Glaciation has played an important but incompletely understood role in the park . Glaciers existed throughout the park area during most of the Pleistocene with smaller ones persisting at higher elevations until comparatively recent times . Lassen Peak is situated at a center from which many of these glaciers originated . Glacial ice that filled Mill Creek ( whose canyon is mostly post @-@ glacial ) , Blue Lake Canyon , Kings Creek Meadows , Flatiron Ridge , Warner Valley and the valley of Manzanita , Hat and Lost Creeks originated from there . Indeed , Lassen Peak appears to be sitting in the depression carved by the Lost Creek Glacier .

Reading Peak formed a second center from which ice moved north into Hat Creek and Summit Creek . Ice moving southward united with some of the above glaciers and emptied into Warner Valley . On the central plateau , the ridge connecting Hat Mountain with Crater Butte served as a divide between ice flowing northward to Badger Flat and Hat Creek and that moving southward to Corral Meadows , Kings Creek and Warner Valley . Ice from Mt . Harkness and Sifford Mountain also wound up in Warner Valley .

The crest of Saddle Mountain served as a divide with ice north of it moving into the depression containing Snag and Butte Lakes , while those to the south entered Warner Valley . The ice varied from a thickness of 1 @, @ 600 ft ( 490 m ) in Warner Valley to much thinner sheets in the higher mountains .

= = = Post glacial to 19th century activity = = =

Subsequent to the rise of Lassen Peak , several dacitic pumice cones developed in a rift extending northwest from the base of Lassen Peak . Then about 1 @, @ 100 years ago several dacitic domes , the Chaos Crags , protruded through these cones and obliterated all but half of the southernmost cone . At least 300 years ago a series of large avalanches , possibly triggered by steam explosions , occurred on the north side of the Crags . These avalanches created their own ' air cushions ' that helped accelerate them to speeds exceeding 100 mph ( 160 km / h ) and push them partway up Table Mountain . The resulting wilderness of debris , the Chaos Jumbles , covers an area of 2 @. @ 5 sq mi ( 6 @. @ 5 km<sup>2</sup> ) . Manzanita Lake was formed as a result of Manzanita Creek being dammed by the debris . Steam rose from the domes of Chaos Crags until 1857 .

Around the mid @-@ 18th century a series of eruptions produced Cinder Cone in the northeast corner of the park , mantling an area of 30 sq mi ( 78 km<sup>2</sup> ) with ejecta in the process . Ash falling on the streams of lava pouring from the cone 's east flank formed the Painted Dunes . A flow of quartz @-@ studded basalt lava ( the Fantastic Lava Beds ) poured from the Cinder Cone and dammed the streams that fed nearby Butte Lake to the north , forming Snag Lake to the south . In the late 18th century Cinder Cone had its most recent eruption and lava flow .

= = = Early 20th century activity = = =

Explosions recurred at irregular intervals on Lassen Peak for most of 1914 . Later , on May 19 , 1915 , a mass of lava rose in the summit crater and spilled 1 @, @ 000 ft ( 300 m ) down the western side of the volcano . Extensive lahars ( mudflows ) were created on the northeastern side as snowbanks were melted . The resulting debris swept down the slope . Divided by Raker Peak , part of this mudflow raced down Lost Creek ; the remaining flow passed over the 100 ft ( 30 m ) rise east of the park road and rushed down Hat Creek . A wide barren swath was torn through the forest .

A great explosion blasted out a new crater three days later on May 22 , 1915 . A volcanic cloud rose 40 @, @ 000 ft ( 12 @, @ 000 m ) , but a portion of the explosive force was deflected downward . The resulting pyroclastic flow of super @-@ heated gas , rocks and ash roared down the same path taken by the mudflow , resulting in further damage along the headwaters of Hat and Lost Creeks . Ash from the eruption blew eastward with some fine ash falling at least as far as 200 mi ( 320 km ) from the volcano .

The last major eruptions of Lassen Peak occurred in April through June 1917 , when a new crater was created at the summit of the mountain . Less explosive activity continued through 1921 . Some authorities , such as the Smithsonian , consider the eruption of Mount Lassen to have ended on June 29 , 1917 .

Since then , the volcano has been dormant , although some steam still rises from small vents in its summit and on its flanks . Pumice ejected during the 1915 eruption of Lassen Peak is conspicuously banded with light streaks of dacite and dark andesite , which appears to represent two distinct magmas imperfectly mixed during the eruption . The 1915 eruption of Lassen Peak was the second most recent volcanic outburst in the contiguous 48 U.S. states ( after the 1980 eruption of Mount St. Helens in Washington ) .

= = Volcanic hazards = =

= = = Direct eruption hazards = = =

The most common volcanic activity over the last 50 @, @ 000 years in the Lassen volcanic area consists of small to moderate @-@ sized eruptions that produce basaltic lava flows and localized ash falls . These eruptions typically last a few months to a year , but may continue for several years .

They can cover more than 1 sq mi ( 2 @. @ 6 km<sup>2</sup> ) with lava flows , build cinder cones as high as 1 @, @ 000 ft ( 300 m ) , and blanket many square miles or square kilometers with ash a few inches ( several cm ) to about three feet ( one meter ) deep . Because these eruptions are relatively nonviolent , they rarely cause human fatalities .

Dacite eruptions in the Lassen area typically begin with steam explosions caused by the interaction of rising magma with ground water . When dacite magma charged with volcanic gases reaches the surface , it erupts explosively , usually as a vertical column of gas and ash that can rise several miles into the atmosphere . Heavy fallback of hot ash and rock fragments from eruption columns may generate highly mobile pyroclastic flows that can rush several miles down a volcano 's slopes and adjacent valleys . Fallout from the eruption column can blanket areas within a few miles ( ~ 8 km ) of the vent with a thick layer of pumice , and high @-@ altitude winds may carry finer ash tens to hundreds of miles from the volcano , posing a hazard to flying aircraft , particularly those with jet engines .

The areas of highest hazard are those that could be affected by pyroclastic flows and lahars ( see map ) . These areas , including Hat Creek Valley , are those in the immediate vicinity and downhill from likely eruption sites . Fallout of ash will affect areas downwind at the time of an eruption . Within the hazard zones , relative hazard is gradational , decreasing away from the location of potential vents .

After an initial explosive eruption , extrusion of gas @-@ depleted dacite magma commonly forms lava domes . Growing lava domes are inherently unstable , and collapse of their steep sides often generates pyroclastic flows of lava blocks and ash that can travel several miles . Such a sequence of events is recorded by the deposits related to the emplacement of Chaos Crags domes between 1 @, @ 100 and 1 @, @ 000 years ago .

Interaction of hot pyroclastic flows with snow and ice can generate highly mobile flows of mud and debris ( called lahars ) that may rush down valleys leading away from a volcano . Because of this , active volcanoes that have a significant snow and ice cover can be particularly dangerous . The lahars that threatened residents of the Lassen area in May 1915 were generated by relatively small eruptions of Lassen Peak . Nonetheless , they traveled down creek beds as far as 12 mi ( 19 km ) and released floods that affected valleys for 30 mi ( 48 km ) downstream .

= = = Non @-@ eruption hazards = = =

Additional volcano hazards at Lassen are rockfalls and landslides not directly related to eruptions . Recently erupted volcanic domes are unstable and can collapse , generating small to large rockfalls . Approximately 350 years ago , collapse of one of the Chaos Crags domes generated huge rockfalls , creating an area now called the Chaos Jumbles . The first and largest of these traveled 4 mi ( 6 @. @ 4 km ) downslope and was able to climb 400 feet ( 120 m ) up the side of Table Mountain . The trigger for the rockfall is unknown , but it was most likely a large earthquake . Normal weathering also weakens fractured volcanic rock and contributes to small rockfalls . In the summer of 1994 , a rockfall of 13 @, @ 000 cu yd ( 9 @. @ 9 × 10 ? 6 km<sup>3</sup> ) occurred on the northeastern flank of Lassen Peak . During periods of extreme rainfall or snow melt , mudflows are sometimes generated by mobilization of loose volcanic debris and soil on the slopes of volcanoes .

The only current visible activity in the Lassen volcanic area is from the various geothermal areas in Lassen Volcanic National Park ; boiling hot springs , bubbling mud pots and fuming fumaroles . Most of these features lie in or are closely adjacent to Mount Tehama 's caldera . In each thermal area , the highest temperature of water generally is close to the boiling temperature at the altitude of the particular spring or fumarole 198 ° F ( 92 ° C ) at Bumpass Hell and 191 ° F ( 88 ° C ) on the northwest flanks of Lassen Peak .

The hottest and most vigorous hydrothermal features in the Lassen volcanic area are at Bumpass Hell , which marks the principal area of upflow and steam discharge from the Lassen hydrothermal system . A prominent steam plume marks the site of Big Boiler , the largest fumarole ( steam and volcanic @-@ gas vent ) in the park . The temperature of the high @-@ velocity steam jetting from it has been measured as high as 322 ° F ( 161 ° C ) . A thin crust of material often covers these

boiling hot features , making them a serious burn hazard to anyone walking off trail . The steam @-@ heated waters of the features are typically acidic and , even if cool enough , are not safe for bathing .