

= Uturunku =

Uturunku (Quechua for jaguar , Hispanicized spellings Uturunco , Uturuncu) is a dormant volcano in the Cordillera de Lipez in Potosí Department , Bolivia . It is located in the Sur Lipez Province , San Pablo de Lipez Municipality . It is in the Central Volcanic Zone of the Andes , and its highest summit is 6 008 metres (19 711 ft) above sea level . The volcano has two summits , with a fumarole field between them . The volcano 's landforms include lava domes and lava flows .

The volcano was sporadically active during the Pleistocene , with the most recent eruption dated at 271 000 years ago . Since then , Uturunku has displayed fumarolic activity . Starting in 1992 , satellite observations have indicated a large area of regional uplift centered on Uturunku , which has been interpreted as an indication of large @-@ scale magma intrusion under the volcano . This might be a prelude to large @-@ scale volcanic activity , including " supervolcanic " activity and caldera formation .

= = Geography and geology = =

Uturunku is a dormant 6 008 metres (19 711 ft) high stratovolcano south of Quetena Chico , in the Altiplano of Bolivia . The edifice has a volume of 85 cubic kilometres (20 cu mi) , covering an area of 400 square kilometres (150 sq mi) on a base altitude of 4 500 metres (14 800 ft) . It is constructed from porphyritic dacite lava flows and lava domes . Andesitic enclaves are also present and some dacites border on silicic andesite in composition . The edifice has been affected by glacial activity . The Lower and Middle Pleistocene lava flows form the base of the edifice and extend 15 kilometres (9 @. 3 mi) away from the volcano . Middle and Upper Pleistocene lavas form the upper part of the volcanoes and extend up to 10 kilometres (6 @. 2 mi) away . According to geological inspection involving both aerial surveys and field work , the longest lava flows appear to generate from the central vent . Flow features on the lavas are well preserved , and are blocky with high fronts . The flows are several tens of metres thick . A sulfur mine (22 ° 14 ' 50 " S 67 ° 10 ' 53 " W) was reported in 1975 . It was based on native sulfur and minor realgar in the volcanic ash , with an estimated 50 000 000 tonnes (49 000 000 long tons ; 55 000 000 short tons) of ore . Laguna Celeste lies at the foot of the volcano and is fed by snow melt from the volcano 's northeastern side . Mama Khumu , a lake on the western side of the volcano , is also fed from the volcano .

Uturunku 's lavas contain biotite , hypersthene , ilmenite , magnetite , orthopyroxene and plagioclase . They also contain inclusions , a few percent andesite , norite and xenoliths derived from the crust containing sillimanite gneiss and igneous rocks . Morphological and chemical analysis of the eruption products indicate that the dacites formed by fractional crystallization of andesite magma . Some of the dacite magma was modified by mixing of dacite and andesite magmas . The magma also underwent oxidation and degassing during ascent . Analysis of the erupted dacites indicate that the magma was nearly water @-@ saturated and stored at depths given differently as 2 4 kilometres (1 @. 2 2 @. 5 mi) or 5 @. 7 kilometres (3 @. 5 mi) by studies , and temperatures of 870 ° C (1 @. 600 ° F) . The chemistry and microstructure suggest that Uturunku magmas formed in magma chambers subject to episodic replenishment with hotter magmas . Major and trace element analysis indicates a substantial similarity of Uturunku lavas to local ignimbrites .

= = = Regional setting = = =

The Central Andes and the Central Volcanic Zone formed in response to the subduction at a rate of about 6 @. 5 centimetres per year (2 @. 6 in / year) at an angle of 25 ° of the Nazca Plate below the South American Plate . The onset of the modern orogeny was precipitated by the breakup of the Farallon Plate 26 mya , resulting in accelerated and steepening subduction of the now @-@ Nazca plate . After a 14 million year phase of shallow subduction , 12 mya the subduction steepened to the current angle of 30 ° by 3 mya . The Altiplano ? Puna volcanic complex (APVC)

formed during this time .

The APVC is an area of the Andes where an upper crust magmatic system has generated large @-@ scale ignimbrite eruptions and calderas between one and ten mya . The melting of the crust that generated this activity is also thought to have contributed to crustal thickening in the area to about 70 kilometres (43 mi) . An underlying area of partial melts (around 20 % volume) with low density and seismic velocity and high conductivity has been identified with a top at 17 kilometres (11 mi) depth . This area accumulates magma at an average rate of 0 @.@ 001 cubic kilometres per year (7 @.@ 6 × 10 ? 6 cu mi / Ms) . This area of melt arches upward and has its thickest and shallowest parts below Uturunku , with the slowest seismic velocity zones located south and west of the volcano .

= = = Local setting = = =

Uturunku is located 70 kilometres (43 mi) west of the main volcanic arc . Starting 11 @-@ 10 mya ago during the Neogene , the Lipez area was affected by ignimbritic activity . Cerro Lipez formed in the Miocene from dacites and rhyolites intruding into Middle Miocene ash flows . Ignimbritic activity includes the 2 @.@ 89 mya Pastos Grandes , the 1 @.@ 98 mya Laguna Colorada and the 0 @.@ 7 mya El Tatio ignimbrite . The smaller Vilama caldera formed 8 @.@ 4 mya and the larger Panizo caldera between 6 @.@ 8 ? 7 @.@ 9 mya . The Chascon ? Runtu Jarita complex was the last active volcano in the area with intrusions dated 85 @,@ 000 years ago . Further west on the border between Bolivia and Chile activity continues today with Iru Phutunqu , Olca , Ollagüe , Putana and others .

The volcano is constructed on local ignimbrite layers , the 8 @.@ 1 mya Vilama and the 5 @.@ 65 mya Guacha ignimbrites . The Lipez ? Coranzuli lineament (also known as the Pastos Grandes @-@ Cojina lineament) runs through the volcano , and seismic activity in the area is aligned to this and neighbouring NW ? SE faults . These fault zones may influence the activity of the volcano and are associated with caldera formation . Volcanoes in the Uturunku area rise about 1 @,@ 600 ? 1 @,@ 700 metres (5 @,@ 200 ? 5 @,@ 600 ft) above the surrounding terrain .

= = Climate and glaciation = =

Present @-@ day climate conditions at Uturunku volcano are scarcely recorded . Most of the humidity comes from the Amazon basin in the east ; this generates a decreasing gradient over the Altiplano westwards . The Lipez area is dry , receiving less than 100 millimetres per year (0 @.@ 12 in / Ms) of precipitation . Because of this insufficient precipitation , there is no present @-@ day glaciation on Uturunku despite the 0 ° C (32 ° F) isotherm being lower than the summit of the volcano and of other neighbouring summits at 5 @,@ 000 metres (16 @,@ 000 ft) .

The presence of a shallow (less than 100 @-@ metre / 330 ft) difference between the altitude of the valley bottom of the southern glacial valley , and its shoulders indicates past low @-@ volume glaciation . Five different moraine stages between 4 @,@ 800 metres (15 @,@ 700 ft) and 4 @,@ 850 metres (15 @,@ 910 ft) altitude have been identified . Striated rocks and roche moutonnées are also present in the area . Based on helium @-@ 3 surface exposure dating , these moraines originated from Pleistocene glacier fluctuations between 65 @,@ 000 and 14 @,@ 000 years ago . The lowest of the moraines , and thus the largest extent of glaciation , coincides with the highstand of the " Lake Tauca " lake episode 16 @,@ 000 @-@ 14 @,@ 000 years ago , where the Altiplano was covered by a large lake . Rapid deglaciation occurred after the disappearance of Lake Tauca 14 @,@ 000 years ago .

= = Eruptive history = =

= = = Pre @-@ Holocene = = =

Uturunku was active between 890 ± 000 and 271 ± 000 years ago . Lavas higher up the edifice are younger and less extensive . The volcano was constructed in two phases dated by argon ? argon dating , one 890 ± 000 ? 549 ± 000 years ago and the younger , less extensive one 427 ± 000 ? 271 ± 000 years ago . The youngest age belongs to the summit lava dome . Older estimates by the Servicio Geológico de Bolivia proposed that the northern and western flows were between 10 and 15 mya old and the summit flows older than one million years .

Two lava domes south of the summit , with a combined volume of 1 km³ (0 . 24 cu mi) , are the oldest structures of the volcano , having formed 1 ± 050 ka and 1 ± 041 ka . Lava flows on the southern and southwestern sides of the edifice have similar ages of 1 ± 028 and 1 ± 018 ka . Subsequently , two lava flows on the southern and eastern side of the volcano and a group of flows on the northeastern side erupted 890 , 714 and 660 ka were the only eruptions until 595 ka . Ten domes and flows were erupted between 595 ? 590 ka , including two large domes located north ? northwest of the summit erupted at the start and end of this period . These domes formed directly on the Altiplano and are 500 m (1 ± 600 ft) high , 1 km (0 . 62 mi) wide and have a combined volume of 0 . 4 km³ (0 . 096 cu mi) . 549 ka the western dome was erupted 5 ± 5 km (3 ± 4 mi) southeast of the NNW domes ; it subsequently collapsed , forming a debris avalanche that covered 1 ± 3 km² (0 . 50 sq mi) . The largest lava flow from Uturunku was erupted 544 ka ; this Lomo Escapa flow flowed 9 km (5 ± 6 mi) over the ignimbrite plain . Based on a thickness of 200 m (660 ft) a volume of 1 ± 7 km³ (0 . 41 cu mi) was estimated from this flow .

Starting from 450 ± 000 years ago , the morphology of the flows change . Between 458 and 387 ka flows and domes are shorter and originate mostly around the summit area ; the longest flow from this phase erupted 455 ka and is 2 ± 6 km (1 ± 6 mi) . The last major pulse occurred 316 ± 267 ka , and its products have dimensions similar to those older than 500 ± 000 . The youngest flow in the southeastern summit area is dated 250 ka .

Volcanic activity at Uturunku was episodic , with bursts of eruptions separated by between 50 ± 000 and 180 ± 000 years of rest . Eruptions were likely voluminous , with lava flow volumes of about 0 . 1 ? 10 km³ (0 . 024 ? 2 . 399 cu mi) erupted in short time periods . Such eruptions originated from ephemeral magma chambers formed by repeated transfer of magmas from the APVC melt generating zone . In these magma chambers , andesites and silica ± rich magmas formed dacites that erupted to the surface when the magma chamber grew to the point of rupturing its walls . Assuming that the magma output of the volcano was a total of 170 km³ (41 cu mi) , the average flux rate was less than 0 . 00027 km³ / a (2 ± 1 × 10 ? 6 cu mi / Ms) , below the average for local volcanoes .

== Recent unrest ==

The volcano has two fields of fumaroles (< 80 ° C (176 ° F)) in the area between Uturunku 's two summits and has caused hydrothermal alteration of country rock . These fumaroles form visible clouds of steam . This heat may have been replenished from the APVC melt generating zone or survived since the last eruption of the volcano . Fumarolic activity is distinct enough to be visible from ASTER satellite image but barely visible from the ground . The temperature of the hotspot has been relatively constant in contrast to Lascar . The presence of lava flows overlying moraines , which indicate post ± glacial activity , is controversial ; the summit lava flows have been glaciated .

Starting in 1992 , and increasing in 1998 , a 70 km (43 mi) wide circular region around Uturunku has been deforming at a rate of 1 ? 2 cm / year (0 . 39 ? 0 . 79 in / year) . Research has indicated that the sources must be deep to create large ± scale ground inflation , but above the partially molten layer of the APVC partial melt zone . A ring of subsidence surrounds the uplift and expands the size of the deformed area to a diameter of 150 km (93 mi) . The total volume changes over 14 years amount to 40 ± 000 ± 000 ± 000 m³ (1 ± 4 × 10¹² cu ft) at a depth of 17 ? 30 km (11 ? 19 mi) below the surface . Magma accumulation rates of 0 . 01 cubic kilometres per year (7 ± 6 × 10 ? 5 cu mi / Ms) have been estimated . These inflation and

accumulation rates are comparable to the inflation rates at Yellowstone Caldera and Long Valley Caldera in the United States and Lastarria (Cerro del Azufre) in Chile. The depth and scale of deformation and the absence of a large @-@ scale hydrothermal system indicates that the ground inflation is unlikely to be hydrothermal. Evidence from prehistoric levels in local lakes does not suggest that such ground movements occurred in the volcano's past.

Anomalous seismic activity was also observed centered in a source 3 ± 4 km (1 @.@ 9 ± 2 @.@ 5 mi) deep , 4 km (2 @.@ 5 mi) southwest of the summit . Microseismic activity was also registered . Such seismicity exceeds that of other volcanoes in the region (with the exception of Lascar during active periods , and Lastarria and San Pedro) and is unlikely to be normal background activity for the area . Some earthquake activity and seismic swarms were triggered by the 2010 Chile earthquake , which may be indicative of unstable hydromagmatic systems or interactions of the magmatic system with far field earthquake waves . Hypotheses regarding the earthquake activity either consider shallow faults deforming in a brittle manner , groundwater movements or a combination of these with a disturbance of a hydrothermal system . The presence of partial melts below the Altiplano ? Puna volcanic complex suggests a magmatic origin of the activity .

Gravimetric data indicate that a vertical low density body connects Uturunku with the APVC magma body at a depth of 25 km (16 mi) . Several such bodies with radii 12 ± 20 km (7 @.@ 5 ± 12 @.@ 4 mi) are found beneath the APVC . In 2013 , del Potro et al. estimated that this body may contain 25 % by volume of molten dacite . The formation of buoyant mobile layers following heating may destabilize this magma mush and cause lavas to accumulate a few kilometres below the volcano and erupt .

= = Threats = =

The magma intrusion rate below Uturunku is considerably larger than the magma output of the Pleistocene volcano , being comparable to the magma flux of historic eruptions and estimates of magma generation rates in local caldera forming magma chambers . Evidence for the formation of such a magma chamber is elusive but might be hidden by the deformation activity of the APVC melt generation zone . Uturunku may be developing into a supervolcano , and a caldera forming super @-@ eruption may occur there ; this possibility has resulted in international media attention .