= El Laco =

El Laco is a volcanic complex in the Antofagasta Region of Chile . It is directly south of the Cordón de Puntas Negras volcanic chain . Part of the Central Volcanic Zone of the Andes , it is a group of seven stratovolcanoes and a caldera . It is about two million years old . The main summit of the volcano is a lava dome called Pico Laco , which is variously reported to be 5 @,@ 325 metres (17 @,@ 470 ft) or 5 @,@ 472 metres (17 @,@ 953 ft) high . The edifice has been affected by glaciation , and some reports indicate that it is still fumarolically active .

The volcano is known for its magnetite @-@ containing lava flows of enigmatic origin . In total , there are four lava flows and two dykes , as well as a formation of uncertain nature . In addition to lava flow structures , pyroclastics containing iron ore are also found within the complex . The magmas formed within a magma chamber with a volume of about 30 cubic kilometres (7 @.@ 2 cu mi) ; whether the iron @-@ rich lavas are native magnetite lavas or were formed by hydrothermal processes acting on regular rock is under debate . After their discovery in 1958 , these iron deposits have been mined . Similar deposits of volcanic iron ore exist in Australia , Chile , and Iran .

= = Geography = =

El Laco is part of the Cordón de Puntas Negras sector of the Central Volcanic Zone , : 681 @,@ 682 directly south of that volcanic chain . It sits atop a quartzite and sandstone basement that was lifted from the seaground during the Acadian orogeny and is of Ordovician age . Later , Mesozoic and Cenozoic sedimentation occurred , which was then buried by Tertiary rhyolites . : 681 @,@ 682 Two major volcanic lineaments cross in the El Laco area . El Hueso volcano to the north is 5 @,@ 029 metres (16 @,@ 499 ft) high and has a basement diameter of 2 @.@ 5 kilometres (1 @.@ 6 mi) . It has a crater with a diameter of 1 kilometre (0 @.@ 62 mi) .

The city of Antofagasta is located 320 kilometres (200 mi) west of El Laco . : 681 Other close towns are Calama and San Pedro de Atacama . The international road connecting Salta in Argentina with Calama in Chile runs close to El Laco . A number of tourist sites are found in the Atacama Desert adjacent to El Laco , and the dry climate also makes the area suitable for astronomy facilities .

= = Geology = =

The El Laco volcanic complex is formed by about seven minor stratovolcanoes and lava domes . The complex started its activity in the Miocene @-@ Pliocene , when porphyric andesites formed a stratovolcano . During the Pliocene , ash and pyroclastic eruptions formed a caldera with a diameter of 4 ? 5 kilometres (2 @.@ 5 ? 3 @.@ 1 mi) , which also contains a central lava dome that formed 6 @.@ 5 million years ago . Finally , probably during the Pleistocene , five iron @-@ rich magmas were extruded , named Laco Sur , Laco Norte and Rodados Negros . Laquito and Cristales Grandes , two abyssal iron magma structures , date back to that era . : 682 ? 684 The volcanic complex is located an altitude of 4 @,@ 300 ? 5 @,@ 470 metres (14 @,@ 110 ? 17 @,@ 950 ft) and covers a surface area of 7 by 5 kilometres (4 @.@ 3 mi × 3 @.@ 1 mi) .

The main summit , Pico Laco , has an altitude of 5 @,@ 325 metres (17 @,@ 470 ft) , although a maximum height of 5 @,@ 472 metres (17 @,@ 953 ft) has also been reported . Pico Laco is an andesitic lava dome with a height of 400 metres (1 @,@ 300 ft) above the surrounding terrain . The dome , with dimensions of 1 @.@ 5 by 1 kilometre (0 @.@ 93 mi × 0 @.@ 62 mi) , has two summits : the higher eastern one and a 5 @,@ 166 @-@ metre (16 @,@ 949 ft) western summit .

Other summits include the northwestern Hueso Chico , a cone with a height of 120 metres (390 ft) above its surroundings and a crater 250 metres (820 ft) wide . This cone is of dacitic composition . " Volcano 5009 " is heavily eroded , and its core of lava and hyaloclastite has been exposed . It has a diameter of 2 @.@ 5 kilometres (1 @.@ 6 mi) . Eruptive activity here probably coincided with glacier activity during the Pliocene , as evidenced by moraines in the area .

Ages of 5 @.@ 3 to 1 @.@ 6 mya have been estimated via potassium @-@ argon dating of the

andesite lavas and subvolcanic rocks . An age of 5 @.@ 3 ± 1 @.@ 9 mya on lavas in the northern part of the volcanic complex is the oldest obtained date . Other dating has resulted in ages of 3 @.@ 9 ± 1 @.@ 3 mya for Pico Laco 's dome , 3 @.@ 8 ± 0 @.@ 9 mya for lavas beneath San Vicente Bayo , 3 @.@ 7 ± 0 @.@ 9 mya for a lava front next to Laco Norte , 2 @.@ 6 ± 0 @.@ 6 for Crystales Grandes , 2 @.@ 1 ± 0 @.@ 4 for Hueso Chico , and 1 @.@ 6 ± 0 @.@ 5 for " Volcano 5009 " . Cordon de Puntas Negras has younger dates . Another date from Pico Laco is 2 @.@ 0 ± 0 @.@ 3 mya . Later alteration included hydrothermal alteration and glacial erosion ; the former has left bleached rocks and exhalation deposits . Some minor metasomatic alteration occurred at the contact sites between andesites and iron @-@ containing rocks . : 684 Hydrothermal alteration has also been described for lower portions of the volcanic pile and probably occurred because of gases escaping from intruded magma . Moraines found west of El Laco were generated by glaciation both on El Laco and Puntas Negras . Surface exposure dating has indicated ages of 226 and 287 ka for some ice @-@ affected lavas . Further , andesitic volcanism in neighbouring volcanoes has blanketed El Laco . : 684 Reports exist of continuing fumarolic activity and hot springs with the deposition of clay and other minerals .

= = Iron @-@ rich deposits = =

On the flank of the volcano , apatite , hematite , and magnetite deposits are found at altitudes of 4 @,@ 600 ? 5 @,@ 200 metres (15 @,@ 100 ? 17 @,@ 100 ft) . The volcano is mainly known for these flows . The deposits lie on top of flat lava flows of andesitic composition , concentrically around Pico Laco . They are named Laco Norte , Laco Sur , San Vicente Alto , and San Vicente Bajo . The deposits consist of dykes , hydrothermal deposits , lava flows , pyroclastics , and subvolcanic structures and were erupted from parasitic vents and fissures . The magnetite is classified as porphyry @-@ like . Apatite is present as an accessory mineral in the lavas and is abundant in the intrusions . Iron @-@ rich zones also formed in tuffs and lavas . Magnetite in the subvolcanic bodies exists in more massive crystals . : 684 The iron @-@ containing rocks include lava flows , ash , and lapilli , as well as ore breccias . The El Laco magnetite lava flows are unique in the world and formed during active subduction .

= = = Individual deposits = = =

Of these deposits , Laco Norte is the largest and was probably separated from neighbouring Laquito by erosion . It is 60 ? 90 metres (200 ? 300 ft) thick and covers a surface area of 1 @,@ 000 by 1 @,@ 500 metres (3 @,@ 300 ft × 4 @,@ 900 ft) . It was erupted from feeder dykes on its southern and eastern end and forms a table @-@ shaped body on a spur , in the shape of a mesa . At Laco Norte , a structure of five layers is found : a basal andesite , ore in pyroclastic form , magnetite lava , pyroclastics which contain ore , and andesite at the top . Laco Sur has a similar morphology and dimensions of 30 ? 70 by 600 by 750 metres (98 ft ? 230 ft × 1 @,@ 969 ft × 2 @,@ 461 ft) ; it has been mined . San Vicente Alto is a lava flow on the upper parts of the volcano (30 by 320 by 480 metres (98 ft × 1 @,@ 050 ft × 1 @,@ 575 ft)) , and San Vicente Bajo is probably a lava dome (250 by 390 metres (820 ft × 1 @,@ 280 ft)) . Laquito (150 metres (490 ft) long and 50 metres (160 ft) wide) and Rodados Nortes (500 by 600 metres (1 @,@ 600 ft × 2 @,@ 000 ft)) appear to be dykes , while Cristales Grandes (80 ? 100 metres (260 ? 330 ft) long and up to 30 metres (98 ft) wide) is more likely a vein and generally shows signs of hydrothermal formation . A magnetic layer of rock spreads north from the volcano , and a large magnetite body has been modelled beneath Pasos Blancos .

= = = Structure and appearance = = =

The magnetite lavas are primarily aa lava , but other surface features are also found , including pahoehoe features . Columnar morphologies are found on the magnetite , implying that they cooled quickly . There is only one other place in the world where columnar magnetite has been found ?

Kiirunavaara , in Sweden . Large tubes coated on the inside by magnetite were formed in the lava by escaping gas . Both before and after the magnetite lavas , layers of magnetite @-@ containing pyroclastics were erupted . A 0 @.@ 5 ? 2 @-@ metre (1 ft 8 in ? 6 ft 7 in) aureole separates the magnetite rocks from the host rocks . The magnetite lava flows are 50 metres (160 ft) thick , the pyroclastics 30 metres (98 ft) and 20 metres (66 ft) respectively . : 684 ? 685 The pyroclastic @-@ like deposits are porous and fragile and show traces of stratification . The pyroclastics at Laco Sur contain spherules of magnetite . An age of 2 @.@ 1 ± 0 @.@ 1 million years has been found for ore by fission track dating . The lavas contain veins likely generated by hydrothermal activity .

= = = Origin = = =

Temperatures estimated for the erupted rocks cover a wide range , with some exceeding 800 ° C (1 @,@ 470 ° F) . These rocks are of enigmatic origin , which may be geothermal or magmatic , with the presence of lava bombs of magnetite lava supporting the magmatic origin theory . Other viewpoints consider the texture and chemical composition of the rocks as evidence that metasomatism of andesitic rocks formed the magnetite " lavas " . The role of a post @-@ magmatic fluid phase , which was inferred from inclusions in crystals , has also been suggested . Some magnetite was oxidized to hematite , : 681 probably under the influence of rainwater as indicated by isotope analysis . Only a minor amount of hematite is primary . Isotope data indicate that the formation of this magnetite magma was accompanied by the segregation of plagioclase . This plagioclase may have generated the rhyodacite lava dome . An iron @-@ phosphate @-@ rich magma generated the magnetite lava flows after release of volatile substances . The magma was probably bordering on forming a two @-@ phase melt containing nelsonite and rhyolite . A favourable tectonic context associated with the compression of the magma chamber and the presence of faults helped with the eruption of the magnetite . : 688 ? 689 The magma formation probably occurred in a magma chamber . During the cooling of the magma , the ores formed . This process was probably not directed by water @-@ rich phases , and the segregation occurred at a shallow depth . High phosphorus and volatile content may have lowered the melting point of the magma and facilitated its eruption , as well as overcoming density @-@ based constraints on the eruption of iron @-@ rich magmas . Suggestions that anatexis of iron @-@ rich sediments generated the iron @-@ rich magmas appear implausible . The ultimate origin of the El Laco iron may be subducted metal @-@ containing sediment .

= = = Human history and exploitation = = =

These iron oxide deposits were found in 1958 . Mining in Laco Sur removed about two million tons of magnetite between the 1970s and 1990s , leaving an open pit exposing 30 metres (98 ft) of rock . In 2009 , these mineral reserves were mined by Cia Minera del Pacifico S.A. It is estimated that the deposit contains one billion tons of ore , consisting of 50 % iron . : 684 The geological interest in these kinds of mineral deposits is enhanced by their frequent association with other minerals , as has been noted at Olympic Dam , Australia . Other magnetite @-@ apatite ore deposits in the Andes are Incahuasi (10 @.@ 3 ± 0 @.@ 8 mya) , 26 kilometres (16 mi) south of El Laco , and Magnetita Pedernales (Tertiary) , about 300 kilometres (190 mi) south @-@ southwest of Laco .

= = = Comparable deposits = = =

The Kiruna magnetites in Sweden resemble the El Laco ones in terms of manganese and vanadium content , and their titanium content is comparably low . Other deposits of volcanic iron ore are the " Chilean iron belt " , the Tertiary Cerro el Mercado deposit in Mexico , the Eocambrian Bafq district in Iran , and the Proterozoic Kiruna field in Sweden . Of these , Sierra Bandera in the Chilean iron belt may be another example of surface volcanic iron ore rather than subvolcanic ore as is commonly assumed of these deposits .

= = Petrology = =

The main rocks of the volcano are andesite and dacite , which contain biotite and pyroxene as well as blebs containing iron oxide . The iron @-@ containing rocks are a less important component . The whole rock falls into the calc @-@ alkaline class of volcanic rocks . The andesites contain plagioclase clinopyroxene , orthopyroxene , and phenocrysts of magnetite . : 681 ? 682 Magnetite , and in lesser measure hematite , are the most abundant iron minerals ; : 685 anhydrite , diopside , goethite , limonite , maghemite , pyrite , : 685 and diadochite are also found . Erupted magma was probably gas @-@ rich , as the magnetite lavas would otherwise have melting points of over 1 @,@ 500 ° C (2 @,@ 730 ° F) . The lavas lost most of their sulfur and phosphorus after their eruption . High oxygen @-@ 18 amounts in the Laco magmas indicate either crustal contamination or isotopic effects during fractional crystallization . Some atmospheric water influence has been inferred from isotope data as well .

Hydrothermal alteration of the central lava dome and iron @-@ bearing deposits has generated alunite , anatase , chlorite , copper veinlets , gypsum , illite , jarosite , labradorite , quartz , rutile , sanidine , smectite , and sulfur . Some of these minerals forms veins inside the rock . : 684 Silification is prominent and has formed cristobalite and tridymite . Elemental sulfur is also found . Vast regions of the volcano have been altered hydrothermally at temperatures of 200 ? 250 ° C (392 ? 482 ° F) , giving the rock a clear appearance . Minor exhalation deposits are also found in the form of sulfates that sometimes conserve conduits . Red @-@ coloured alteration halos occur in andesites adjacent to iron deposits , probably due to iron input .

= = Environment = =

The vegetation in the area is primarily low bushland . Short @-@ tailed chinchillas can be found at El Laco .

El Laco has a classical cold mountain climate at the line between the dry Altiplano with summer precipitation and the hyper @-@ arid Atacama Desert climate . A nearby weather station (23 ° 45 ? S 67 ° 20 ? W) at 4 @,@ 500 metres (14 @,@ 800 ft) altitude showed an average temperature of 2 @.@ 3 ° C (36 @.@ 1 ° F) in 1991 , with strong short @-@ term variability . The majority of precipitation falls during southern hemisphere summer ; winter snowfall has been recorded . Air humidity recorded in 1991 was 10 ? 30 % .