A Guide to the Geology of Lauca National Park

G. Wörner

Geowissenschaftliches Zentrum, Goldschmidtstr. 1

37077 Göttingen, Germany, Gwoerne@gwdg.de

For those interested learning more about the geology of the Central Andes this short geological tour guide describes the roadside geology between the town of Arica (northern-most Chile) and the Lauca National Park with Parinacota and Pomerape volcanoes (see photo above).This road is frequently travelled by tourists because the Lauca National Park and its spectacular volcanoes are among the the top scenic and touristic highlights in northern Chile.

In Chile, traveling from Arica to Lago Chungara and in the Lauca National Park, you can learn about the geological history of the Central Andes. Magnificent views of the Cordillera and its valleys are windows to their evolution during the past 25 million years. Towering volcanoes, some active, some only dormant, and rivers running down to the Pacific Ocean keep shaping this impressive landscape.

HOW THE ANDES WERE FORMED

The Earth's plates move at speeds of 5 to 10 cm per year. Oceanic plates grow constantly at ridges on the ocean floor in the middle of the ocean basin, sand – when old and cold enough – will sink back into the Earth's mantle at their margins. The Andes are such a "convergence zone" where the Pacific plate is subducted below South America. This causes earthquakes, the formation and ascent of magma from depth, and a chain of volcanoes along the plate boundary. Compression comes from both sides: subduction to the east and movement of the South American plate from the west. This compression at the continental margin has caused the thickening of the continental crust during the past 25 million years. This compression was aided by heating and softening of the crust due to magmatic activity and the hot mantle beneath. Folding and faulting resulted in stacking of crustal slices on top of each other. When the crust thickens, its roots are pushed down into the mantle and its summits will be raised to higher elevations. Heating of the crust causes melting and highly explosive volcanism in addition to the volcanoes that have their roots in the mantle below.

The Altiplano–Puna plateau was the result of this process. When the Western and Eastern Cordilleras emerged, a closed basin formed between the mountain ranges. Water cannot escape towards the oceans. Thus, sediments collect, and water evaporates, leaving behind the well-known salars. Uplifted high mountain ranges are typically subject to strong erosion. However, the western side of the Andean plateau is a desert and erosion is minimal. Therefore – apart from younger volcanoes – we find one of the oldest landscapes on Earth in the region between Arica and Lago Chungara.

VALLE DE LLUTA

Stop 1

Valle de Lluta (km 22) at Poconchile. Taking a 1 km detour south, just before Poconchile, you see at the base of the valley slope layers of sandstones, mudstones, and gravel that were formed by erosion after the initial phase of uplift of the Andes 25 to 20 million years ago. Overlying volcanic deposits (white/pink and brown layers), called "Oxaya-ignimbrites", are the result of extremely explosive eruptions. Mixtures of ash, pumice, and gas moved downslope in glowing clouds, covering everything beneath. This magmatism is due to melting of the thick continental crust around 22 to 19 Ma. **GPS: 18°26′56″ S, 70°03′58″ W; Elevation: 555 m**

Photo 1: View from above Poconchile, top of road that connects Lluta and Azapa Valleys. Pink and brown layers are massive volcanic deposits (ignimbrites) from glowing ash clouds. The extensive, inclined ignimbrite surface at the distance is disturbed by the Lluta collapse that forms the humped topography across the valley.

Viewpoints along the road (km 32). From a distance, you can observe the layers, which form a wedge-shaped ramp between the Andes and the coast (Photo 2). **GPS: 18°25′02″ S, 70°02′28″ W; Elevation: 759 m**

Photo 2: View across the Lluta valley floor towards flat-lying sediments overlain by 20-23 million year old ignimbrites.

"Lluta Collapse" (km 46). Climbing the flank of the Lluta valley, across to the North, the pancake layering of sediments and ignimbrites is seen flat on the horizon. (center and right in photo 3) However, directly across the valley, these layers are strongly disturbed (left side of photo 3). Large blocks (>>100 m) are broken and tilted. Uplift of the Andes and steepening of its western slopes was not accommodated sufficiently by erosion because the climate changed to a desert about 12 million years ago. Therefore, the steepened mountain flank collapsed in an enormous landslide that covered >300 km^2 up to 600 m thick about 7 million years ago. **GPS: 18°24′43″ S, 69°58′29″ W; Elevation: 1,182 m**

Photo 3: View from the road climbing the southern flank of the Lluta valley. Across, you see flat-lying sediments and Ignimbrites and snow-capped Taapaca volcano in the distances towards the ENE (off the photo to the right).

Stop 2

Collapse scar at Pampa Plazuela (km 57). To the east, you see the scar of the collapse as a giant amphitheater on the horizon ahead. To the north and northeast, across the Lluta Valley, the surface of the sediment+ignimbrite "wedge" is undisturbed. Snow-capped Volcan Taapaca appears at the horizon towards the northeast. Driving further into the Cardones valley, older rocks (granites of Cretaceous age: >65 million year old) are covered by the ignimbrites. Eventually, you can see white ash, which partly fills the valley. It is the so-called "Lauca-ignimbrite" that erupted 2.7 million years ago as a hot ash cloud north of Lago Chungara. From there, it has travelled down the Cordillera and left thick deposits in the valleys and on the plains. **GPS: 18°20′15″ S, 69°01′35″ W; Elevation: 1,300 m.**

Photo 4: View across Pampa de Plazuela near the Borax processing plants. Steep escarpments to the right (east) and ahead formed when the entire western slope of the Andes collapsed. Vast rock masses were displaced >20 km and 600 m thick towards the ocean.

Stop 3a

Do not miss to visit Mallku, a small settlement in the near the road, where Andrea and Alexis provide shade and provisions, desert stories, and tea made from local plants. **GPS: 18°24′04″ S, 69°38′57″ W; Elevation: 3,124 m**

Stop 3b

Mirador Pucara de Copaquilla (km 90). The Western Cordillera in the east formed by strong tectonic movements from the East to West along N-S directed faults. Badlands below this viewpoint indicate unconsolidated, young sediments. These rest on 19–20 million year old ignimbrites. To the south, you see flat lying gray sediments that fill the depression above a tilted block in front of you. The tilting is to the east and therefore against the general slope of the Andes. This resulted in a sediment trap and a basin that is now filled by these younger sediments that represent debris from the Cordillera. Ash layers within the sediments were dated and gave a maximum age of 10.5 Ma. Tilting thus occurred at about 11 million years ago. About 2.7 million years ago, these sediments were covered by the horizontal layer of the Luaca ignimbrite, which is exposed in the distance but also directly behind you at the road across from the parking at Copaquilla. The uppermost reach of Rio Azapa has since cut back into the titled "Oxaya" block, the overlying sediments and the Lauca ignimbrite on top. You even can see some vegetation at the valley bottom near the village of Copaquilla. This process is still going on**. GPS: 18°23′29″ S, 69°38′32″ W; Elevation: 3,100 m.**

Photo 5: View from the Inka fortress (Pucara Copaquilla) to the south.

Stop 4

Mirador de Socoroma (km 110). The Lauca ignimbrite is discerned across the valley as a white filling of older valleys above Socoroma. The road now winds along the slope of the Western Cordillera to Putre. Rocks are strongly deformed sedimentary and volcanic rocks that were strongly altered by hot fluids in the crust near magmatic intrusions during the recent evolution of the Andes (8-15 million years ago). **GPS: 18°16′21.8″ S, 69°34′48.9″ W; Elevation: 3,490 m**

Stop 5

Mirador de Putre (km 125). The valley of Putre (Photo 6) is partly filled by volcanic avalanche deposits from Taapaca volcano hovering above the small town. This volcano grows as a cluster of domes since about 1.5 million years ago. Domes form when magma erupts but the lava is too viscous and therefore cannot flow. Steep dome flanks destabilize, collapse, and blocks and ash move down the slopes in glowing avalanches. These volcanic deposits have filled the valley floor and provided flat ground for building the town and cultivating the fields. One of the most recent eruptions was dated only a few thousand years ago. Taapaca volcano is presently dormant but can awaken any time in the geological future. **GPS: 18°12′27″S, 69°33′31″ W; Elevation: 3,707 m**

Photo 6: View across Putre towards Taapaca volcano.

Stop 6

Below Taapaca Volcano (km 140). Here you can observe one of the most recent deposits of a glowing avalanche that rushed down the flanks of Taapaca. Looking to your right, a mixture of fresh gray blocks (a rock called “dacite”) and loose volcanic material partly fills the valley. When you break one of the blocks, you can note the radial columnar cooling joints, which prove that they were still hot when emplaced. **GPS: 18°12′48″ S, 69°38′44″ W; Elevation: 4,010 m**

Photo 7: Block-and-ash deposit from a ~10,000 year old glowing-avalanche that formed as a result of a dome collapse near the summit of Taapaca volcano (to the N and out of sight in this valley).

Stop 7

Mirador Pampa Chuca (km 152). The Western Cordillera lies behind you and the “Nevados de Payachata”, with Parinacota and Pomerape volcanoes rising as part of the active volcanic chain in the east (Photo 8). Most other peaks are extinct, but you may see fumaroles on Guallatiri in the south. Extinct volcanoes are identified by deep erosion and glacial valleys. Here, they typically have ages from 10 million to about 1 million years. Cerro Guane Guane is not a volcano but a tilted block of older rocks, including Oxaya ignimbrites. Volcanism in the Andes is caused by the sinking oceanic plate below the western edge of South America. During subduction, it loses water at about 120 km depth. This water reduces the melting point of the

overlying mantle rocks and magmas rise to the surface. These volcanoes have their roots at such depth and form a chain parallel to the coast. When magmas cool and crystallize, they form “andesites”, the most common volcanic rocks in the Andes. **GPS: 18°15′48.3″ S, 69°20′38.2″ W; Elevation: 4,345 m**

Photo 8: View of Parinacota and Pomerape volcanoes. The latter is partly hidden behind Cerro Guane Guane, which is the only peak seen from this viewpoint that is not a volcanic edifice.

Stop 8

Parinacota. After passing the village of Chucullu, you may turn to the left to the old colonial village of Parinacota. It is located within a large area of boulders and hummoks that formed by a gigantic collapse (see Stop 9). **GPS: 18°12′08″ S, 69°116′04″ W; Elevation: 4,435 m**

Photo 9: The old colonial church in the village of Parinacota

Stop 9

Mirador Cota Cotani (km 172). The deposits of a volcanic flank collapse from Parinacota fill the depression before you. The collapsed mass left a landscape full of large blocks and depressions between them (the Cota Cotani lakes). Parinacota volcano started its life about 160,000 years ago and reached its full height about 10,000 years ago. The giant collapse occurred about 8,800 years ago and decapitated most of the old edifice. Since then, the "new" Parinacota was rebuilt by frequent eruptions. Compared to other volcanoes in the area, Parinacota is a youthful volcano that may just be at the beginning of its long eruption history. With its high rate of eruptions, future eruptions are very likely. It is debated when it will erupt again. **GPS: 18°15′00″ S, 69°10′36″ W; Elevation: 4,585 m**

Photo 10: Hummocky surface formed by a gigantic flank collapse of Parinacota volcano (about 8,800 years ago). Each of the thousands of little mounds all around represent a block that slid down during the collapse from the volcano, which was left beheaded after this catastrophic event. Since then, the new youthful" and conically shaped stratovolcano has been rebuilt by frequent eruptions.

Stop 10

Mirador Chungara. The location at the CONAF hut near Lago Chungara is probably your last stop. Across the lake, Parinacota rises from the lake at 4,561 m to 6,348 m above sea level. Lago Chungara is considered the highest lake of its size on Earth. To the southeast, across the lake, is Sajama. It is an extinct volcano and the highest peak in Bolivia. The current form of Lago Chungara developed after the collapse of Parinacota volcano about 8,800 years ago when the masses of debris blocked a river at the outlet. The present cone of Parinacota that you see was built only in the past 8,800 years. Across the lake, at the base of the volcano, several black lava flows formed from centers on the lower flank. These are the youngest lava flows, just a few thousand years old.

Photo 11: Parinacota (6,348 m) at the border between northernmost Chile and Bolivia (18°09'48''S, 69°03'35''W) as seen from near Lago Chungara, the highest lake of its size in the world. The dark lava flows at the base of the cone flowing towards the lake represent some of the most recent eruptions from the volcano. The volcano is dormant but could erupt at any time in the geological future. Grazing wild vicuñas (a member of the camel family) on a small swampy bofedal are in the foreground.

Tourist Information

Transportation

Private cars and tour buses follow Route 11 from Arica (Chile) to Chungara (Chile). Gasoline is not regularly available but may be purchased from drums at Zapahuira, in Putre, and - with luck - in Chucullu. Public transportation will get you to Putre and back (Empresa "La Paloma"), but not to Parinacota and Chungara. You may hitch a ride from Arica to Chungara with one of the buses to LaPaz, but don't count on one to get back to Arica.

Lodging

There are hotels in Putre but lodging elsewhere is difficult. Refugios of CONAF (the Chilean National Forest Corporation) exist at Putre, Parinacota, Chungara and Surire. You can get information from these refugios. However, when going to visit any of the CONAF refugios, make sure you contact CONAF in Arica first to make sure the refugio is staffed.

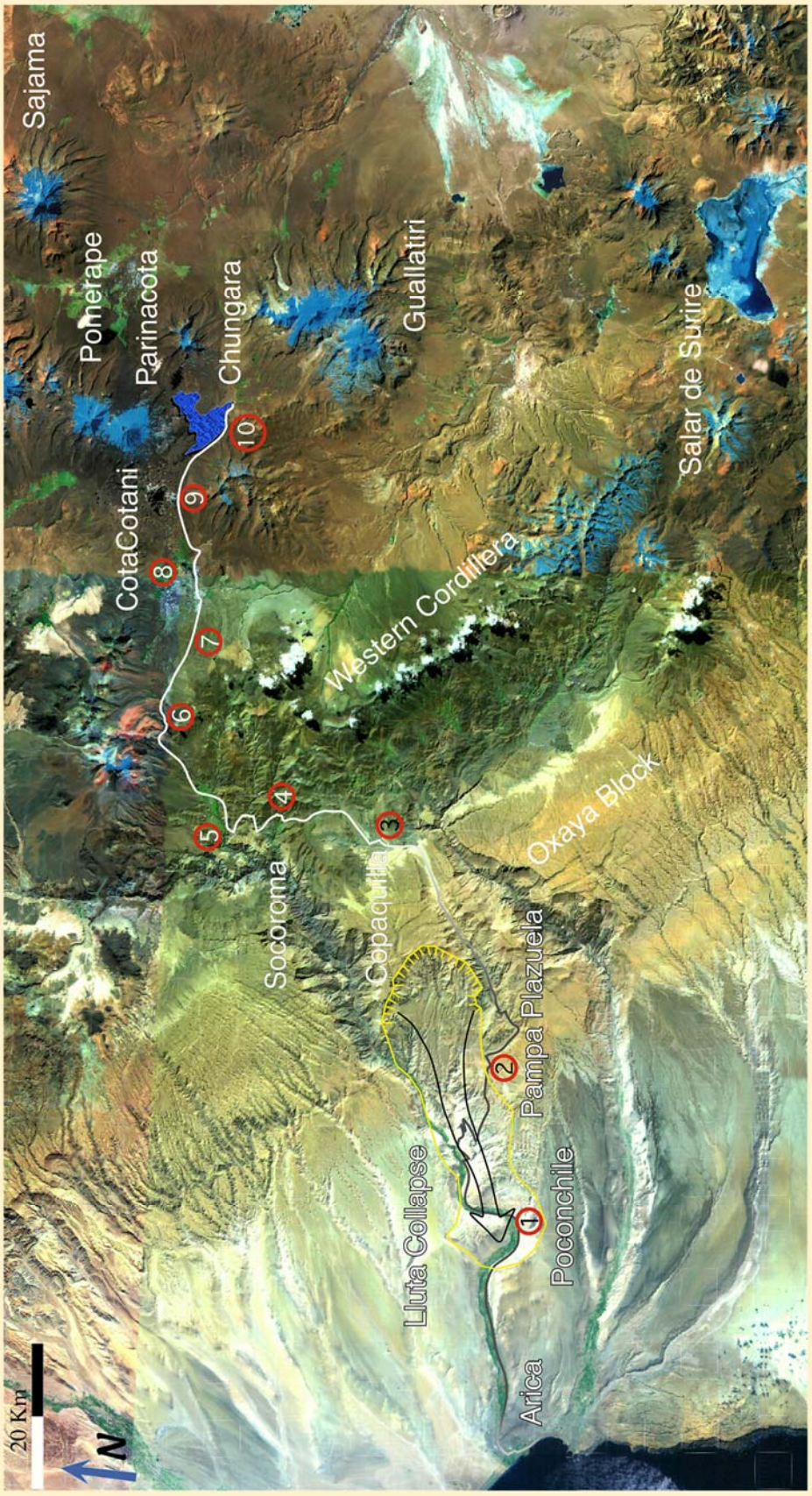
Food

You will find a shop and rustic restaurants in Zapahuira and Putre, but you cannot buy any food or water on the Altiplano. With luck, the truck stop in Chucullu will serve simple meals. A good place to stop on your way up or down is the posada and village Mallku near Copaqilla in the desert right at the main road. Andrea and Alexis will serve tea and snacks and provide interesting information about the region.

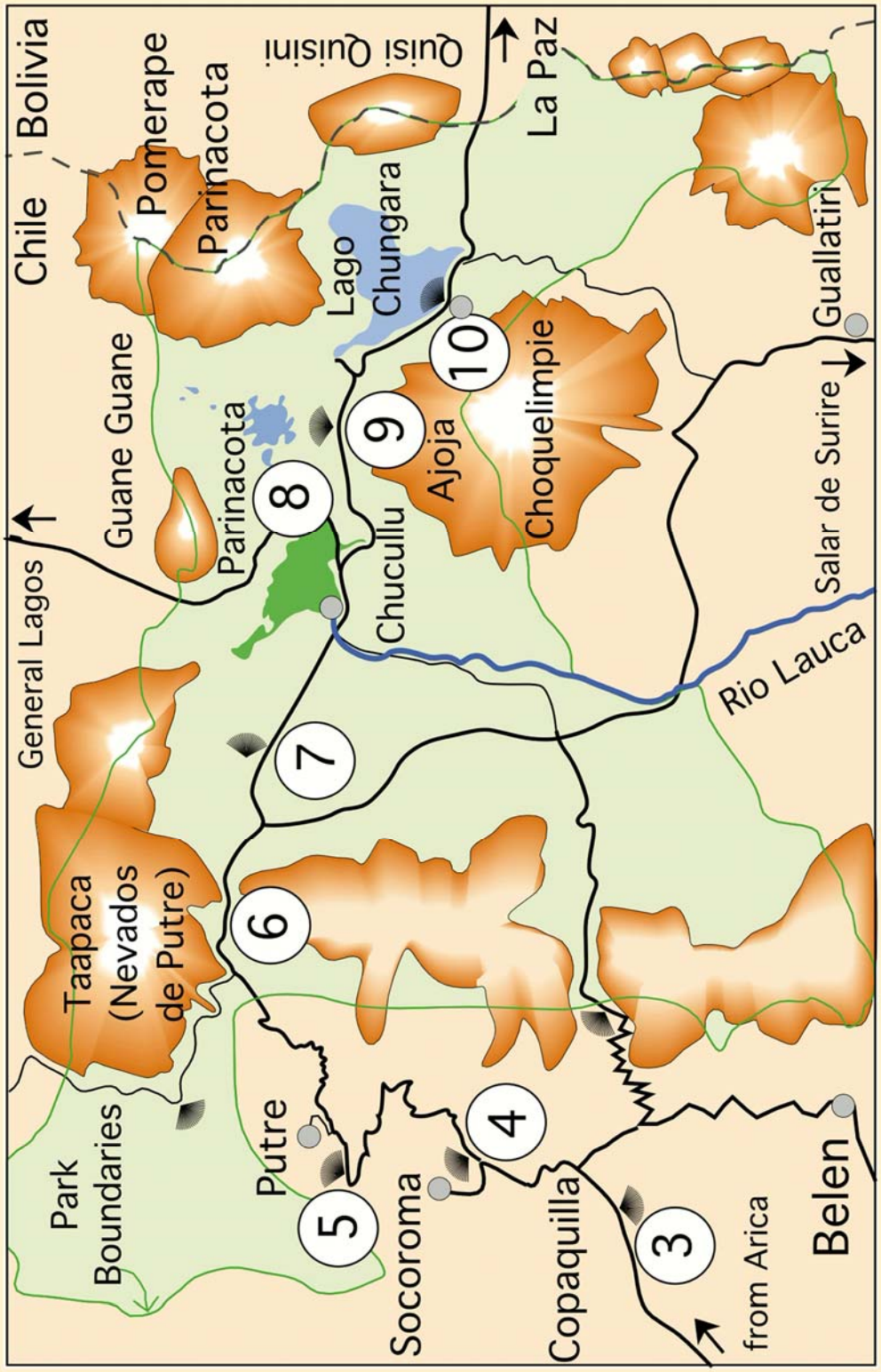
Souvenirs and Handicrafts

Take out what you take in and leave nothing but your footsteps. Remember, this is a national park and no animals, plants, or rocks can be taken out. If you want to bring home souvenirs, there are huts in Parinacota and Indian ladies at Chungara and at the Mirador de Putre that will sell blankets, jumpers and other handicrafts (mostly!) made of alpaca and llama wool.

For further information, please contact the CONAF headquarters in Arica, Vicuna Makenna # 820, Casilla 1484, Chile. Tel. +58 250570- 250739-250207 and www.conaf.cl



Satellite image of the area between Arica and Lago Chungara within the Lauca National Park in northernmost Chile.
Stops indicated and numbered as described in the text.



Schematic map of the Lauca National Park with stops indicated as described in the text.