Storke Memorial Field Course to Peru 2019

Field Notes

Lamont-Doherty Earth Observatory/Columbia University

Organizers:

Bar Oryan **Elise M. Myers**

Day 1

Travel to Paracas, Peru from NYC - no notes

Day 2

Elise Myers and Bar Oryan
Islas Ballestas & Paracas National Reserve Day

Islas Ballestas

7:45am: Pick-up from hostel (Posada Pinguino) for transport to office Like Xplorer.

8am: Tour via boat for islands begins

In the port (where the boat is docked), there are many small boats, a lot of them labeled "Pisco". These boats are primarily used by fishermen from the Pisco region. Some of the boats that travel out further (15-20 days spent in the open waters) have harpoons to catch giant squids and blue sharks (called diamantes here). The smallest boats only leave port for about 15-20 hours. Resting on top of these boats, you can see cormorants and pelicans.

8:10am: First stop at -13.7916, -76.303 (lat, long) @ sea level

On our way, we see guano covered arches and cliff faces. Here, the humidity aids in compacting the mud to get harder layers. The red color that we see in these cliff faces is iron (Fe) oxide. There are abundant brown Pelicans and Peruvian boobies, the latter tucked in cliff face crevices. Seagulls from this region, also in high abundance, sometimes eat the chicks of the Peruvian boobies. From show we can see some bedding in the cliff faces. The smallest bird we saw was the Inca tern; we also saw many turkey vultures. Our guide noted that, during mating season, pelicans have a yellow colored head (feathers) and a multicolored beak.

This is also the place where you can view the impressive Candelabra geoglyph that was created pre-Inca, by the *** people. The Candelabra was etched 30-40 cm deep into the limestone rock face (roca calcarea), about an order of magnitude deeper than the Nazca lines. One legend describes this geoglyph as a cactus because of the healing properties of cacti. Also, it was used in navigation by fishermen.

on the way to the 2nd stop, we saw the flippers of sea lions and 1 dolphin dorsal fin was also spotted. Our guide told us, upon our return, that seeing a dolphin was good luck.

8:30am: Second stop at -13.741173, -76.38645 @ sea level

Our guide informed us that Islas Ballestas is the colonial name for the islands, arches, and caves in this area. The used to be called Islas guaneras (sp?), which is the original name in Quechua. This is related to the massive amounts of guano (i.e. bird poop) that are

found on these islands. *The last exportation of guano was in 2009, before the area became a protected area; 10,000 tons of guano were harvested by hand by 200 people and then exported*. Our boat passed by a multiple old docks/rigs for exporting guano. Now, because these islands are protected, there are guards stationed on these islands. We passed a station (Sistemas islas, islotes, …*) and all waved to the guards protecting this important natural system.

We were told by our guide that we would see about 1 million birds and we did see quite a few. We saw, Humboldt penguins, Peruvian boobies, guanay cormorant and a peregrine falcon. Humboldt penguins tend to nest at the upper part of these rock/arch formations and return their after fishing/swimming. The guanay cormorant is sometimes confused for the Humboldt penguin from afar because of their white bellies. One distinction is that male guanay cormorants have a crest on their heads. We also saw massive, sequential formations of guanay cormorants flying above us, reminiscent of Alfred Hitchcock's "The Birds".

We also saw Galapagos crab (yellow/red) and sea spider (another type of crab that looked black). At this stop we happened upon a sea lion flipping around a fish that it was eating; our guide commented that it was likely a tuna. Sea lions consume about 15 kilograms of shrimp and fish per day by sea lions, including anchovy and sardines. Mother and calf (baby) sea lions are more common to be seen from December to May, though we did see a few pairs. Large male sea lions can weigh between 300-400 kg. Female sea lions are pregnant for 11 months. Sea lions reportedly put their heads back to aid in digestion.

9:25am: Passing by Isla Bonita to head back to the port

At this moment, we started heading back to shore that this point. Our guide mentioned that that we can see granite rock that eroding over millions of years, eroding away the hard rock substrate. We saw interesting breaking patterns in the red rocks on the cliffs.

*Break from ~10-11am, during which we did some grocery shopping for our picnic lunch, withdrew money (look for BCP ATMS - you'll thank us later), and grabbed snacks before our adventure.

Paracas National Reserve

11am: Before the start of the tour, at Like Xplorer office

Peru is divided politically into departments, provinces, and districts. This district has only 4,000 inhabitants, but encompassing a huge area (about 80 square km south of Paracas). A lot of this area is a desert, national reserve, which means not buildings can be made there. The road leading to the national reserve that we used separates the city and the national reserve (east of the road was the city). Most of the houses in the area are vacation homes and hotels. There are spaces for 4,000 visitors to the city, matching the number of inhabitants. On our way to our first stop, we saw the Bay of Paracas, which

has ocean water coming in from North to South inside the peninsula curve. This leads to minimal waves and a relatively protected bay. Along the coast of the bay, we see black soils/sands which are swampy (mantanosa). In this area, there are abundant nutrients and invertebrates to sustain the bird population. Also, we passed Chilean Flamingos (Flamencos Chilenos), which migrate in July/August and stay until December before they go to rest in the mountains. Some of the flamingos are local (from the Peruvian mountains), but a few are from Miami, noted by tags on them.

11:30am: Visitors Center & Centro de Interpretacion (-13.86909, -76.2727865)

To the east, we see red hills, which are actually part of an archaeological site. Under those hills are homes from about 1.2 kyr that have been covered over time. These homes were accessed by the roof because this provided more protection from the harsh environment (sandstorms, cold weather, harsh sun, harsh desert conditions, and no materials for building above ground). The homes were made of the same material as the Candelabra. We also golden rocks in a road cut outcrop that are supposedly of marine origin because this region used to be under water. Our guide mentioned that the Nazca plate is coming in under, which lifts Peru and moves it eastward towards the land direction. The amount of uplift/movement did not seem well-constrained, so warrants further research.

In the Centro de Interpretacion, you can learn about the history and biodiversity of the reserve and the surrounding area. For example, 15% of the Peruvian population only speaks Quechua, primarily located in the Andes. Paracas derives from the Quechua words "para" which means rain and "aca" which means sand. So, this area is characterized by sand falling like rain (or very windy with sandstorms). In the center of the first room there is a cool exhibit on sand origins and the resultant grain sizes. One final fun fact, is that 35 mya, the Andes cordillera was 1000-1500 meters above sea level, during the time of the giant penguins that were 6 meters tall (Inkayacu Paracasensis).

A couple of people then went into the museum, while the rest of us went to look at flamingos, or "big pink birds having fun" (unnamed source).

-13.866507, -76.27220 - Along our walk to the flamingos, we saw a small patch of snail fossils (carcoles fosiles). Also here, we saw 3 types of halotolerant vegetation: sesuvium partulacastrum, distichilis spicata, crexsa trucillensis. There were also, what looked like plastic bags littering this flat stretch of land out to the flamingos, but they were actually seaweed/marine algae that were drying and decomposing.

left at 12:30

12:50pm - Catedral Rock Formation (-13.936419, -76.283076 @ 44.01 m)

From this viewpoint, we were able to see the Catedral rock formation that used to be attached to the main cliff by an arch. However, the arch collapsed following the 2007 earthquake. At a beach nearby called "Devil's Beach", fishermen collect various marine organisms. Only fishemen travel to this beach because of the hazardous conditions to get

down. While looking more closely at the Catedral, a potential intrusion was spotted near where Peruvian boobies were clustered on the rock formation.

13:30 - Playa Roja (-13.893597, -76.296232 @ 92 m)

The sediments of this beach are said to be igneous in origin and the weathering of the pink grandiorite is suggested to be why this beach's sand is red (or "roja"). From here, you can see both the north and south side of the peninsula. Directly across the beach, you can see a large cloud that is touching the ground on the hills/mountains. This area is wetter and has vegetation, unlike the surrounding desert conditions. Further to the left of this cloud-covered region is a dark black rock that shows layering at a steep angle. This formation, at the end of the opposite beach edge, is black because it is full of vegetated fossils from about 300 mya. This formation was full of coal and was extensively mined, giving way to this beach's name: Playa La Mina. There is now an abandoned coal mine at the edge of this beach and it is more known for the beautiful views.

On this beach, we saw a massive stranding of what look to be pelagic red crabs (*Pleuroncodes planipes*, also called red tuna crabs), a species of squat lobster that have been reported to wash up in large numbers along the coast of California (sources below). These pelagic red crabs migrate primarily by drifting with the tide, winds, and currents. El Niño events in particular, where southern waters move poleward, cause many of these crabs to spread around southern and central California coasts. Massive strandings were first reported in 1859 and the cause of death is said to be that the local waters are much colder (Michael Shane, director of fisheries enhancement at Hubbs-SeaWorld Research Institute). In some beaches, like Bahia Magdelena, the strandings appear to be more annual occurrences (Aurioles-Gamboa et al 1992). Another theory for these strandings is that females release larvae in upwelled water and the crabs would breed (greatest upwelling winter → spring), which makes it more likely for them to be caught in currents and subsequently die in accidental strandings. According to Aurioles-Gamboa et al., the breeding season is from December to April (for crabs off the west coast of Baja California), with a peak in February and breeding possible twice per season. The year of this trip was during a particularly weak El Niño event and during the transition from winter to spring in the southern hemisphere, which may have been linked to the massive strandings of this pelagic red crab.

Sources:

- Aurioles-Gamboa et al. 1992 - Annual mass strandings of pelagic red crabs…
- National Geographic 2018 - Thousands of Tiny Red Crustacean Strand on California Beach
- Phys.org 2016 - Thousands of tiny red crabs stranding on California beach
- IFL Science 2016 - Thousands of dead lobsters are washing up on beaches in California

We also learned from our tour guide at this spot that there are lizards/geckos living in the desert region, as well as vampire bats. The bats feel on the blood of sea lions on the nearby coast. The general population of animals in the coastal desert region is minimal.

**lunch break ~14:00-15:00*

15:20 - Playa La Mina (-13.91115, -76.317603 @ 7.78 m)

Our guide with LikeXplorer Peru was amused by our enthusiasm and allowed us an additional stop to Playa La Mina. At this section, we discussed the mining history of the area a bit further. On the way to the beach, we found an outcrop that appears to be a sequence of shallower marine sediments on top of deeper marine sediments, with gypsum forming and being altered later.

Day 3

Chris Carchedi and Nick O'Mara

Huacachina Sand Dunes and the Nazca Lines

Huacachina Sand Dunes

8:32am: Pick-up from Paracas hostel (La Posada Pinguino) for travel to Nazca

9:21am: Driving by local farmland (grapes, peppers)

9:55am: Arrive at Huacachina Sand Dunes

Upon arrival to this oasis tourist town in the middle of the dunes, the group contemplates the possibility of renting dune buggies and riding into the horizon MadMax-style and ultimately decides on the nearest path up the ridge of a large sand dune. Sweaty, winded, and acutely aware of the academic's physical fitness, the group settles in a divet in the dune's ridge to discuss science. Bar opens a discussion by asking why there might be a desert in this location before describing the many types of deserts. The group agrees that together subtropical, rain shadow, and coastal effects may combine to create this arid environment. The conversation shifts to dune structures themselves. Are large obstacles necessary to build a dune, or simply a small irregularity in the surface on which grains can accumulate? We discuss factors that control dominant dune wavelength, such as humidity, grain size, and local wind patterns. Finally, Jonny concludes the lesson by differentiating Rayleigh-Taylor and Kelvin-Hemholtz instabilities in a tangent.

11:44am: Descend sand dune and refuel with ice cream

12:06pm: Grocery shopping at Metro Cebcosud

12:40pm: Begin hunt for Kelvin

1:12pm: Target Kelvin spotted and retrieved

2:51pm: Sight potential dikes in hilly roadcut

3:08pm: Stopped in traffic from local funerary procession in Rio Grande

Nazca Lines

3:30pm: Lunch stop and drone test flight

4:15pm: Arrive at Nazca Lines viewing platform

Here we talk about Nazca Lines and the viewing platform

Three features are visible from the viewing platform: the hands, tree, and lizard. The latter was bisected by the roadway. At the base of the viewing platform, artisans sold souvenir pebble carvings of the Nazca Lines. Some of these were then wrapped in playful newspaper advertisements.

4:50pm: Depart for hostel in Nazca

6:22pm: Arrive at Nazca hostel (Bris Hotel Nazca)

Day 4

Lloyd Anderson and Nick O'Mara

Coastal Geomorphology and Drive to Arequipa

6:55 am: Bus arrives and we depart from Bris Hotel, Nazca

7:22 am: Transit toward the coast

As we approach the coast, we descend toward a marine layer of clouds. A wind field is visible in the distance with only the tips of the blades peaking over the thick clouds.

9:02 am: Pitstop for olives and honey (-15.66909, -74.52521).

The stark and barren coastal desert is patched with rivers leading to the sea. In these valleys olives trees are cultivated and the sides of the highway are lined with stalls selling the fruits of the local's labor. We stop for a salty snack.

9:33 am: Ocean side view of the Rasa

Fig 4.1: View of rasa at the edge of the Pacific

We stop to view the Rasa right before the coastal town of Takana. Rasa are gently sloping sedimentary features of paleoshorelines that are used to study past rates of tectonic uplift. Lucy describes the subduction of the Nazca plate beneath the South American plate to the group, and we discuss whether the subduction of the Nazca Ridge leads to regionally faster uplift compared to the rest of the Peruvian coast. We are within the transition zone of flat-slab subduction where the Nazca plate is dipping beneath the South American plate at a low angle to the north to higher angle subduction to the south. Lloyd shares with the group how coastal geomorphology and cosmic exposure dating (e.g. Be-10) can be used to constrain past rates of tectonic uplift.

10:22 am: Stop for a hearty breakfast of yogurt, granola and bananas

11:32 am: View point of marine terraces near the town of Chala.

Here we were still observing the general Rasa structure, but there were more well-developed terrace features here. We returned to the discussion of whether flat-slab subduction due to the Nazca Ridge accelerates uplift or not.

Fig 4.2: Marine terraces

3:23 pm: Stop for gas and ice cream

For much of the drive from Chala along the coast to the southeast, we were bounded on the left by steep, towering sedimentary slopes and to our right by steeper rocky cliffs that plunged to sea level.

4:14 pm: Stop for lunch at Restaurant Arely

We were treated to one of the most cost effective meals of our lives S/8 (~$2.40) for soup, an entree, and a drink. We also had the somewhat surreal experience of watching Babe: Pig in the City in Spanish while we ate.

10:12 pm: Arrive at hostel

We arrive bleary-eyed and sleepy after a long day of travel, but still have just enough energy to enjoy some ordered in pizza on the balcony before bed.

Day 5

Henry Towbin
Hike El-misti volcano and raft the Chillin river

Day 6

Jonathan Lambert and Josh Russell
Drive to Puno: Pillones Waterfall, Stone Forest Imata, and more

8:27 am: Pick-up from Arequipa hostel (La Puerta del Sol) for travel to Puno
11:20 pm: Arrive at tuff outcrop along the side of the road. (-16.06788, -71.36430 @ 3,900 m)

This stop was a spur of the moment suggestion of the driver's. We first discussed the river running through the tuff, which had some interesting fluvial sedimentary deposits within the channel. There appeared to be vegetation on these in-channel sedimentary deposits, contributing to accretion on the small islands (Fig 6.1)

Before settling on the theory that the surrounding rock was mostly tuff, we had discussions about whether it was substantially sandstone or igneous in origin. A good bit of this discussion took place in reference to the rock in Fig 6.2, which shows distinct layers and weathering patterns. See Figure 6.3 for a view of the broader environment.

Figure 6.1: Small islands within the river channel. The islands are primarily made of the surrounding rock material (tuff), but accretion of vegetation over time is noticeable, likely contributing to further accretion (positive feedback).

Figure 6.2: Rock showing distinct layers and weathering from riverine environments, with people for scale

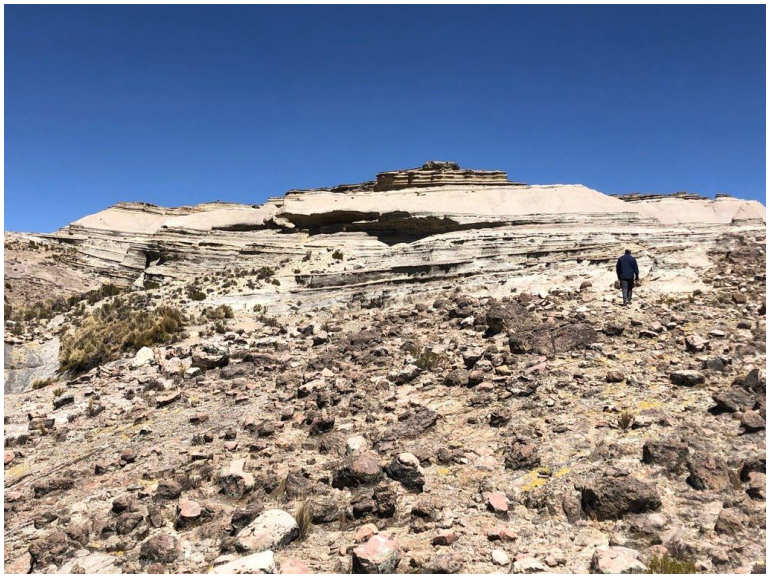

Figure 6.3: View of tuff layers (downriver) at the outcrop stop

1:05 pm: Pull over to view active eruption of Sabancaya volcano (-15.87987, -71.15342)

Sabancaya, meaning “tongue of fire”, is a stratovolcano in the Central Volcanic Zone of the Andes that has been active since early November 2016. After noticing the ash plume in the distance, we pulled over to take a closer look (Figure 6.4). We stayed to observe and take pictures for approximately 15 minutes and saw what appeared to be a second pulse of ash rising as we were leaving. The driver said that seeing eruptions like this is pretty commonplace.

Sources:

- Global Volcanism Program, 2019. Report on Sabancaya (Peru). In: Crafford, A.E., and Venzke, E. (eds.), Bulletin of the Global Volcanism Network, 44:6. Smithsonian Institution.

Figure 6.4: Eruption of Sabancaya as seen from the road between Arequipa and Puno

1:43 pm: Mountain Caracaras Bird Sighting (-15.85200, -71.10800)

We had trouble finding the entrance to the waterfalls. Upon asking for directions, we spotted three mountain caracaras scavenging in the parking lot (Fig. 6.5). The mountain caracara is a bird of prey that is found in the high Andes. It tends to nest on cliffs and often feeds in groups, primarily on rodents, birds, arthropods, and carrion.

Figure 6.5: Mountain Caracara

Sources:

- The Cornell Lab of Ornithology - Mountain Caracara

1:47 pm: Arrived at entrance to Pillones Waterfall (-15.89074, -71.17098 @ 4,413 m)

A small local shop where tickets were purchased and the dirt road to the waterfall was opened

2:06 pm: Arrive at parking lot of Pillones Waterfall (-15.87917, -71.17940 @ 4,398 m).

The waterfall cuts through mainly ignimbrite and as seen in Fig 6.6, diverges into two separate channels/waterfalls as it descends. However, it returns to a single channel down valley. Some of the crew hiked to the bottom of the waterfall to closer observe and were able to get nearly to the base. However, some people chose to conserve energy at the high altitude and remain near the parking lot.

Figure 6.6: Pilones Waterfall, cutting through ignimbrite and splitting into two channels as it cascades downward

3:29 pm: Arrive at Stone Forest Imata (-15.91061, -71.04342 @ 4,485 m)

The Stone Forest consists of ignimbrite columns that were formed by preferential erosion of the surrounding rock, leaving chimney like structures (Fig. 6.7). It was unclear what made the columns different from the surrounding material such that they were left standing. Large green moss/lichens were observed on many rocks. These were sometimes very green and sometimes faded/yellow. However, they were hard in texture (Fig. 6.8). We hiked around the forest for approximately 30 minutes and also saw chinchillas (Fig. 6.9) and vicuñas (Fig. 6.10).

Figure 6.7: Rock Forest with an apparent cross-section of a rock in the foreground, and highlighting the unique shapes of the rocks in the background (likely due to preferential weathering)

Figure 6.8: Lichens or moss growing on the side of a rock in the “rock forest”

Figure 6.9: Curious chinchilla inspecting our group.

Figure 6.10: Immature vicuña feeding from its mother.

5:42 pm: Arrive at Laguna Lagunillas Lookout (-15.71538, -70.80968 @ 4,390 m).

This valley is likely glacial in origin, with a “U” shape observed due to glacial scouring (Fig 6.11).

Figure 6.11: Launa Lagunillas Valley looking west toward the sunset, with half of the "U" shape seen in the left cliff due to glacial scouring

9:12 pm: Arrive at Puno hostel (Ayma Hostel Puno) (-15.83817, -70.02846 @ 3,855 m)

Day 7

Josh Russell and Thomas Weiss

Lake Titicaca, Uros Islands, and Free Time

Lake Titicaca and Uros Islands

9:04 am: Pickup by Llary Tours

During our drive, our tour guide talked about the history of the region. Puno is in the Puno region and is pre-Incan, dated to 200 CE. There are 1.2 million people living in the region and 200 thousand in the city of Puno. Many of the residents speak the indiginous language Aymara. The main industries in the region are crop and dairy farming, fishing, and gold, silver, and lithium mining. Of the 4,000 varieties of potatoes in Peru, 800 are grown in the Puno region. The two main breeds of dairy cows in the region are brown swiss and holstein. People in the region live to ~95 years old on average and some live to 110. Our tour guide attributed this to the cancer preventing effects of black quinoa which is a staple in Puno diets.

The Uros people built the Uros islands and date to the 12th century. They came from Polynesia by way of the Amazon. Originally, the Uros people used bamboo to build islands on the lake, but when they discovered the reeds that grow in lake Titicaca, they started to use those to build more substantial islands and building houses on them.

9:16 am: Arrive at the main port of Puno and board a boat (-15.83541, -70.01495)

During the boat ride our tour guide talked about the lake, sharing information that is in the pre-trip section of our field guide. We observed several species of birds including the Titicaca grebe (Fig. 7.1), white-tufted grebe, Andean duck (very similar to the North American ruddy duck), slate-colored coot, Andean gull, and neotropic cormorant.

Figure 7.1: Titicaca grebe found almost exclusively in and around Lake Titicaca.

Figure 7.2: On Lake Titicaca looking west towards Puno.

9:47 am: Beginning of the Uros Islands (-15.82015, -69.97269)

After driving through a path through the reeds, the boat stops at a booth to pay an entry fee that is included in the cost of the tour. There is a grounded island with a soccer field.

9:57 am: Visit Suma Uro island and its inhabitants (-15.81130, -69.97285)

Our tour guide talked about how the islands are made and life on the island and the residents joined him for some demonstrations. We visited Suma Uro island which means beautiful sunrise. Four families live on the island for a total of 15 people. The families elect a leader who serves a one year term and is in charge of assigning comunal jobs to each family. They send their children to the mainland everyday to go to school.

The totora reeds are very important to the people living on the island. They grow to be about three meters tall and have three sections. The white section is eaten like a banana or in a salad and is healthy because it has iodide. It is also used as a toothbrush because it has fluoride and as an alternative to a wet towel for cooling one's neck. The flower is also good to eat and is used to help pregnant women dialate and is good for prostate health.
The islands take approximately a year to build and can last for up to 45 years. The process begins in the rainy season when lake levels are high causing the roots of the reeds to spring up. At this time, the islanders cut the roots into 1 m deep blocks. They used to use eucalyptus to cut the blocks, but they now use metal saws. The blocks are then tied together using synthetic rope and anchored to rocks on the bottom of the lake. The island we visited was made of 27 blocks of different sizes, connected to 10 separate anchors, and was floating in 10 m of water. After ~eight months, the roots of the blocks grow together to form one large platform. After the blocks are connected, they are covered with ~1-2 m of reeds that are compacted by jumping on them. Extra layers of reeds are placed below the houses to reduce humidity. Cooking is done on top of stones by burning dry reeds.
The islanders collect birds eggs and domesticate some birds. Every Saturday they go to the market and trade for food that they don't grow. The islanders have solar panels to generate energy to power their lights and TV
Following the presentation by our tour guide, the islanders showed us their houses then showed us tapestries and ornaments they made that we could buy.

1:44 am: Visit a second comunal island for passport stamps

Tourists have the option to pay S/.10 to take a traditional wedding boat to this island or take the original boat to this island. The island has a restaurant, a small shop with food, and restrooms. Uros Island passport stamps are available from the shop for S/.2. There is also a hole in the island where a net holds trout that are being farmed.

12:40 pm: Arrive back at the port

1:04 pm: Lunch and free time

Day 8

Lucy Tweed and Kelvin Tian

Drive from Puno to Cusco

8:30 am: Depart from Ayma Hostel

10:00 am: Triangle mountain at Pucara

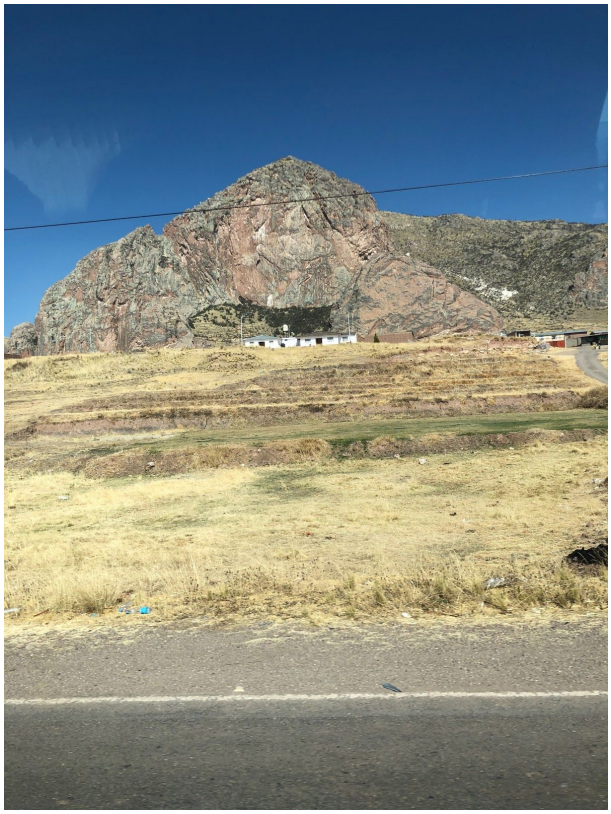

Figure 8.1 Drove by this mountain and stopped by a restroom with stores for ~20mins
11:52am: Arrived at La Raya mountain pass and talked about mountain building and altiplano

Figure 8.2 La Raya mountain pass, facing SE

Figure 8.3 Looking NE, at the Eastern Cordillera, Johnny was explaining the glacier

Figure 8.4 Looking NE, with a cool looking animal

14:30 pm: Arrived at Raqchi temple discussed why Volcano Quinsachata far away from volcanic arc can have volcanism and hiked up the rocky mountain made of extrusives

Figure 8.5 Raqchi temple

15:10 pm: arrived at the top of the hike

Figure 8.6 Top of the hike, Raqchi temple is “blocking” the edge of the lava flow

15:30 pm: visited Andahuaylillas church

Figure 8.7 Andahuaylillas church

19:00pm: Arrived at Chusay Rooftop Homestay hostel

e

Day 9 - Machu Picchu

Henry Towbin

5:30am Depart from hostel (Chusay Rooftop Homestay) via bus to Poroy Train Station

7:30-11am Train ride to Aguas Calientes

Train tracks run through the Sacred Valley of Peru. It is the route that the Incan Empire used

to Machu Picchu

Figure 10.1 View from train roof windows.

Figure 10.2 Stepping off the Hogwarts express…

Access to the famous archaeological site is closely controlled. Tickets much be purchased weeks in advance and are limited to ~2000 people per day. Each person must be accompanied by an accredited tour guide and tour groups at assigned times.

Our tour guide Edgar said that the wall was not to fortify the Machu Picchu from attackers but instead to mark a geologic fault. I have not found literature placing a fault in this particular place but feel it was worth mentioning.

Terraces were used to grow food but not enough to fully feed population

The Temple of the Sun. The central window aligns perfectly with the sunrise during the winter solstice to illuminate the central stone altar.

Machu Picchu’s granite masonry is perhaps the most famous example of Incan Imperialbuilding style. Irregularly sized rectilinear blocks were perfectly fit together with stunning precision and no mortar between them. Our guide told us that Machu Picchu exhibits 13 building styles found around the Incan Empire. The granite was car

Granite

Day 10

Jonny Kingslake and Thomas Weiss
Humantay Glacier and Lagoon

Humantay Glacier and Lagoon

4:42 am: Depart from hostel (Chusay Rooftop Homestay) for transport to Humantay Glacier
6:39 am: Stop at a shop to buy tickets for the hike (-13.51141, -72.52745)
7:09 am: Ticket checkpoint on the road to the glacier (-13.48600, -72.53042)
7:37 am: Enter the Humantay Glacier valley (-13.43970, -72.55170 @ 3,573 m)

> At its maximum extent during the Last Glacial Maximum, the Humantay Glacier had grown to fill this valley. Terraces carved by flow of water around the glacier are said to line the valley walls, but we were unable to identify them. The maximum extent of the glacier outside the valley is unknown. A river running through the valley has carved through the typical broad U shape of a glacially carved valley and resulted in a V shape

at the beginning of the Humantay Glacier Valley. The erosional effects of the river lessen further into the valley and the morphology of the valley takes on more of a U shape.

9:00 am: Arrive at the parking lot and begin the hike (-13.40015, -72.57239 @ 3,828 m)

The road ends at a parking lot where the hike begins. Restrooms are available in the parking lot. Follow the trail out of the parking lot. At -13.395508, -72.573558 take a left at the fork in the trail toward the cliff to avoid walking through private property. After leaving the cliff, the trail moves into the middle of the valley passing by a campground. From the middle of the valley, hikers can see two moraines from the Humantay Glacier and one from Nevado Salkantay all dated to the Little Ice Age (~1300-1850). The cause of the Little Ice Age is still up for debate, but hypotheses include a reduction in solar output, changes in ocean circulation, and decreased human population. One moraine from each glacier dated to 8-10 kya is also visible from the center of the valley. These moraines are the result of a Southern Hemisphere summer insolation minimum caused by Southern Hemisphere summer occuring when the Earth is farthest from the sun in its annual orbit. The 8-10 kya glaciers can be distinguished from the Little Ice Age moraines by their more rounded morphology and because they have been covered by vegetation. After passing the campground, the trail veers left past a restaurant and bathrooms toward Humantay Glacier and away from the Nevado Salkantay valley. After passing the restrooms, the slope of the trail increases and winds its way over soil and small metamorphic rocks, primarily schist with some gneiss and phyllite. Hikers have the option to rent a horse to ride to the base of the Humantay Glacier Little Ice Age moraine. Part way up the hill, there is a second trail that splits from the main trai and gives hikers the option to climb the Humantay 8-10 kya moraine and walk along the ridge.

From this hill, gaps in the Humantay moraines are apparent. These gaps are erosional and due to glacial lakes overflowing the moraines. Once these lakes exceed the level of the moraines, they overflow and easily erode the moraines because they are made of unconsolidated sediments. Such overflow events are often a result of rapid melting of the parent glacier and are a hazard in the Himalayas. There is a large drainage gully that winds its way through the moraines.

11:00 am: Arrive at the lagoon (-13.38122, -72.5876 @ 4255 m)

The trail goes through a gap in the Humantay Glacier Little Ice Age moraine to arrive at Humantay Lagoon. There is a large relatively flat platform between the moraine and the lagoon that offers beautiful views of both the Lagoon and the glacier the perfect opportunity for a picture. We stopped for a snack break and to discuss the processes that drive glacial formation, morphology, and size described in the pre-trip portion of the field guide. The platform was not very crowded as we arrived, but became more crowded as the day went on. Paths lead up to the ridge of both lateral moraines. The top of the west moraine offers views of the end of the valley where there is another Little Ice Age moraine, a waterfall, and outwash deposits.

1:27 pm am: Begin the hike back to the parking lot

This is an out and back trail, so follow the same path to the parking lot

1:42???? pm: Arrive at the parking lot and car and depart for the hostel

4:42???? pm: Arrive at hostel

Day 11

Lloyd Anderson and Jonathan Lambert

Vinicunca (Rainbow Mountain)

~5:00 AM: Depart from Hostel (Chusay Rooftop Homestay) for transport to Vinicunca (Rainbow Mountain)

The driver was at a different corner than originally stated, causing a slight delay (original departure was scheduled for 4:30). However, the roads to Rainbow Mountain are potentially new, so it took less time to arrive at the mountain than the quoted 3.5-4 hours.

~7:20 AM: Stop at bathrooms/welcome center along the way up to buy tickets for hike

7:56 AM: Arrive at Vinicunca parking lot (-13.86995, -71.33223)

Apply sunscreen, prepare and pack lunch, drink water and mentally and physically prepare for high elevation hiking conditions. From the parking lot we could see extensive lateral and terminal moraines across the valley. These moraines were formed by previous greater extents of the mountain glaciers in this region (Fig 11.1). Mount Ausangate is the largest mountain in the area and these moraines are potentially derived from glaciers radiating from it. A muddy glacial outflow lake just below the current glaciers could also be seen from the parking lot.

Figure 11.1: Moraine ridges potentially associated with previous glaciations of the valley near Mount Ausangate

~8:30 AM: Begin hike

The beginning of the hike was relatively flat and easy-going, with bathrooms available for the first ½ to 2/3 until beginning ascent up to the main Rainbow Mountain viewpoint. Most of the view in this part of the hike was to the left of the glacier and glacial valley. Kettle lakes were abundant.

9:33 AM: Reach Lower Rainbow Mountain Viewpoint (-13.86921, -71.30293)

This was a close-up view of Vinicunca and too close for the quintessential photo seen in postcards and commercials. However, this close-up view provided a good vantage point for seeing the details of the mountain as well as the many birds of prey that rested on the colorful mountain. Walking on top of the famous part of Rainbow mountain is blocked off and forbidden. Food was available for purchase from local vendor stalls atop the viewpoint.

~9:45 AM: Reach Upper Rainbow Mountain Viewpoint (5,036 m) (-13.86783, -71.30299)

This was the quintessential view of Rainbow Mountain. Many tourists take photos here, and there is also a very good view of Mount Ausangate from this viewpoint.

11:00 AM: Lunch Break and Discussion (-13.87072, -71.30490)

We stopped on the shelf of a rock after the junction of the main Rainbow Mountain trail and the Red Valley spur to have lunch . Here we talked about the possible anticline structures (Fig 11.2) exposed along the near flank of the Red Valley mountain (Hatun Rit-iyoq). We tentatively concluded that the folding we observed was related to how the paleosols forming the banded “rainbows” had been uplifted. Fig 11.3 shows the rock which we ate atop and is a clear visual of the angle of the stratigraphic units. The mineralogy of the region was also discussed (i.e. red/pink is paleo ultisols, brown is younger conglomerates, purple is marlstone, etc.). See chapter in pre-trip report for full discussion of mineralogy.

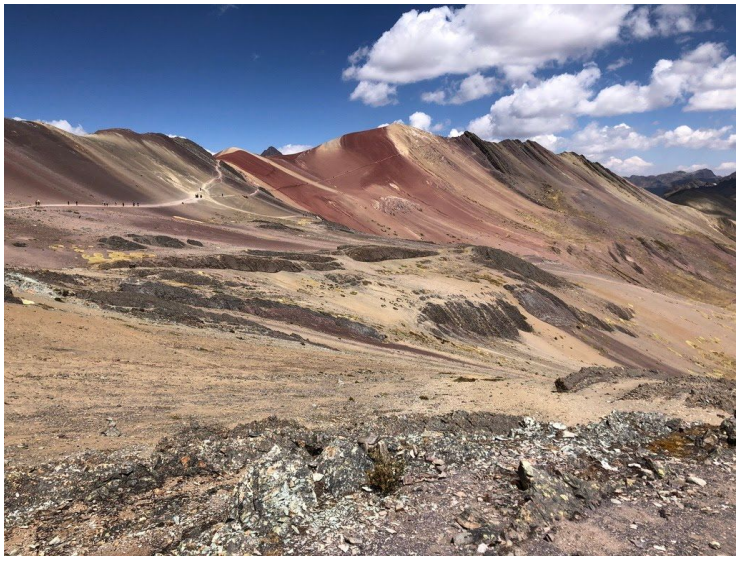

Figure 11.2: Anticline in the red background, which was discussed in relation to the folding and uplift of the larger region.

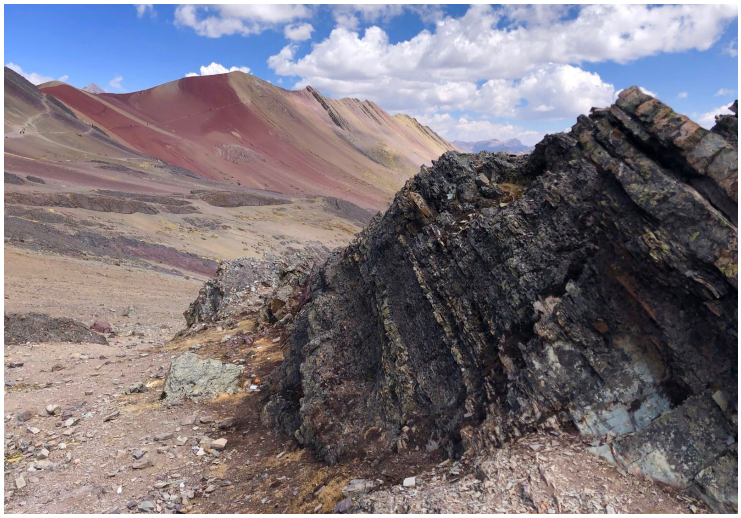

Fig 11.3: Foreground: rock atop which we at lunch and discussed the geology of the region; angle of stratigraphic units is clearly seen. Background: anticline within the red and gold/yellow stratigraphic units.

12:21 PM: Arrive at peak of Hatun Rit-iyoq (5,069 m) (-13.87587, -71.31223).

Here we had a stunning view of the red valley, Rainbow mountain, Mount Ausangate, and the glacial valley. We walked along the side of the ridge to arrive here and then ascended upward to this peak, which is higher than the Rainbow Mountain viewpoint and arguable a better view, as it gave a 360-degree perspective on this dynamic region.

1:24 PM: Descent to valley floor (-13.87707, -71.32992).

After descending from Hatun Rit-iyoq on the other side of the mountain we had been hiking, we walked along the valley floor On this walk around the backside of Hatun Rit-iyoq, we observed similar folding structures that we had seen at lunch earlier (Figure 11.4)

Figure 11.4: Continuous stratigraphic horizons observed in the valley (relatively near parking lot)

2:20 PM: Drive Back

Viewing terminal moraines in valley while driving away from Vinicunca (potentially a succession from Little Ice Age to as old at MIS-4). Extensive agricultural terraces of varying ages were also observed on the drive back in the Valley, with rockfalls and mudslides interrupting their structure periodically.

~5:15 PM: Arrive back at hostel

Day 12

Chris Carchedi

Maras Salt Mines and Travel to NYC from Cuzco

Maras Salt Mines

8:45am: Pick-up from hostel (Chusay Rooftop Homestay) for transport to Maras Salt Mines

During the van ride, a previous conversation is continued by Henry regarding weathering rinds. We talk about how, in some cases, the weathered rind of a rock can be more resistant to erosion compared to the unweathered core.

9:45am: Pass ticketing checkpoint for entry to Maras Salt Mines

9:49am: Overlook stop at rim of gorge containing Maras Salt Mines

(-13.29873, -72.15361 @ 3130 m)

Here, the group sees its first glimpse of the more than 3,500 evaporating ponds that make up the cooperatively-organized Maras Salt Mines. Chris explains why the salt produced here is considered to be ecological: supersaline spring water is directed downhill by a maze of thin channels to fill each pond without the need of pumping. The same Urubamba River that snakes through the Sacred Valley can be seen at the bottom of the slope.

10:07am: Walk down slope towards salterns and pass evaporitic layers
(-13.30377, -72.15478 3042 m)

Along the trail to the next overlook point, the group discovers remarkable evaporites in the rock cliffs. Chris recalls that the rocks belong to the Yuncaypata Group, a ~2000-m thick layer rich in reworked marine sediments dating back to ~110 Ma. Interactions between groundwater flow and these evaporites produce the saturated springs that feed the evaporating pools. Henry begins pulling out large samples of gypsum from the matrix and passing them around. We see a variety of crystal habits, which Lucy explains is the result of both composition and growth conditions. A discussion sparks concerning the precipitation series of evaporites from seawater. With the help of Google images, we quickly find a helpful figure that illustrations precipitation in the following order: calcite from 0 to 68% of water evaporated, gypsum from 68-88%, halite from 88-97.5%, and finally more exotic magnesium sulfates from the last dregs of saturated fluid. Some of the pools appear darker in color and we deduce that these pools must be early in the evaporative process compared to their lighter neighbors. At the end of the trail, we are rewarded with a view of the supersaline spring, encrusted in white evaporites. A salt worker wades through ankle-deep pools in a pair of rubber boots, shoveling red-brown evaporites out of the system. A sheltered observation deck sits a few meters above the uppermost pools providing an exquisite view of the salterns. There, Chris answers remaining questions regarding the evaporative process, which is outlined earlier in the field guide. In order to leave ample time for travel, we begin our trek back up the hill past a bazaar of small artisanal salt shops. Tiny bags of salt make for great souvenirs with the barbeque-flavored smoked salt a crowd favorite.

11:11am: Travel from Maras Salt Mines to hostel (Chusay Rooftop Homestay)

12:31pm: Lunch and packing

A charged conversation arose over the release of the new *Star Wars IX* trailer.

3:45pm: Pick-up from hostel for transport to Alejandro Velasco Astete International Airport in Cuzco