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Notes on the HMRSC-VIII Field Excursions

Viktor Kaufmann
Graz University of Technology, Austria

The HMRSC-VIII post-symposium field excursion was organized by Néstor Jiménez and his colleagues from the Institute of Engineering Geology and Environment of the Faculty of Geological Sciences, Mayor de San Andrés University, La Paz, Bolivia. It took place in the Easter Week from 23-28 March 2005 and actually consisted of four single excursions. The first three excursions each lasted one day, and the last one three days. Throughout the excursions detailed information was given to the participants, however, no special field guide was provided. The purpose of the present notes is to briefly summarize the itinerary (shown in Figure 1) of the field excursions, highlighting the geographical locations, and addressing the issues discussed. Further reading is listed at the end of each section. Photographs and the sketch map were provided by the author.

Figure 1: Sketch map showing the route of HMRSC-VIII field excursions.

23 March, 2005: Yungas (La Paz – Coroico – La Paz)

Figure 2: North Yungas Road descending to Coroico. It is known as the world's most dangerous road.

The Yungas (Yungas Bolivianos) are located east of the Cordillera Oriental and comprise an interesting transition zone ranging from the high Andes (> 4000 m) to the tropical lowlands of the Amazon rainforest (approx. 200 m above sea level). This ecological belt is most diverse in terms of flora and fauna. Temperature (ranging between 10°-26°) and precipitation (ranging between 200-3500 mm) are the main influencing factors. The part of the Yungas situated at the eastern side of the Cordillera Real is called Yungas de La Paz. Various altitudinal zones can be distinguished (see García-Lino and Palabral-Aquilera, in this volume). Fog is present almost all the year around. Moisture is brought by easterly winds from the lowlands. In many places the tropical forest is cut down to make way for the cultivation of crop plants. Coffee, citrus fruits and, typically, coca are grown in an altitudinal range between 1200 and 1800 m due to the mild climate.

Cotopata National Park, located northeast of La Cumbre, is well-known for its rain forest and wildlife. It was founded in 1993 and comprises nearly 59,000 hectares. The Cantuta (*Fuchsia buxifolia*) is a flower found in the high valleys of the Yungas, and is considered the national flower of Bolivia.

The North Yungas Road, connecting La Paz (3600 m) with Coroico (1750 m), is still an important road for bringing goods from the lowlands to the highlands and vice versa. This road (98 km in length) is extremely dangerous. It is very narrow and no guardrails prevent vehicles from toppling down the steep slopes (see Figure 2). Dense fog and rain may hamper visibility. Mud on the road is especially dangerous. On average over 150 people are killed every year on this road. A second, less dangerous road has now been completed. However, the older road, built in the 1930s by Paraguayan prisoners, is still frequently used, nowadays also by fearless tourists and adventurous down-hill bikers.

We started in La Paz in the morning and followed the road to La Cumbre (4650 m), which is the pass crossing the Cordillera Real. From this point there is almost a vertical drop of 3000 m to Coroico, which is 50 km driving distance away. Left-lane driving is mandatory along the most dangerous part of the road (after Chuspipata). This facilitates the more precise and accurate navigation of the downhill moving cars and trucks.

During this spectacular bus drive some stops were made to enjoy the scenery (tropical forest, steep valleys, waterfalls, landslides, etc.). Our destination, Coroico (3200 inhabitants), is the capital of the North Yungas and it is an important political and industrial center of the region. Wood products, fruits and coca are produced for the La Paz region. Moreover, Coroico is well-known for its beautiful tropical environment and its recreational resorts. People from La Paz (Los Paceños) like to spend their weekends and holidays in Coroico. Our lunch break was at Hotel El Viejo Molino. After a short stop at the main square in Coroico we returned to La Paz on the same road we had come.

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24 March, 2005: Cordillera Real (La Paz – Chacaltaya Glacier, Zongo Glacier – La Paz)

Figure 3: Refugio Chacaltaya. The mountain hut belongs to Club Andino Boliviano (CAB).

Figure 4: Ascent to Chacaltaya Peak (5395 m). View in northerly direction with Chacaltaya Glacier and ski lift to the left and Refugio Chacaltaya to the right.

Figure 5: View from the miners' cemetery at Milluni towards Nevado Huayna Potosí (6088 m).

Figure 6: View from the LIA moraine (meteorological station at 5200 m) towards the accumulation zone of Zongo Glacier, Huayna Potosí (6088 m).

Figure 7: View from the orographic right LIA moraine to the snout of Zongo Glacier. The left lateral moraine and a proglacial lake can also be seen.

Figure 8: Group photo of the participants of the field excursion to Zongo Glacier. Parking area at Zongo Pass (4770 m).

The Cordillera Real is an ice-covered mountain range east of La Paz, measuring 280 km in length and 35 km in width. It comprises some 600 peaks, of which six summits are higher than 6000 m. The highest mountain, Illimani at 6439 m, can be seen from La Paz. From a glaciological point of view, Nevado Chacaltaya and Nevado Huayna Potosí are of special interest. In each of the mountains one glacier has been selected for long-term monitoring, i.e., Chacaltaya Glacier and Zongo Glacier, respectively. In the past two decades Bolivian and French glaciologists (see references) have been jointly investigating glacier changes in these areas. According to their geographical position they belong to the so called tropical glaciers, which are very sensitive to changes in climate.

Chacaltaya Glacier was visited in the morning, Zongo Glacier in the afternoon. Thomas Berger from IRD (Institut de Recherche pour le Développement, France) was our guide. In the following the two test sites are discussed in more detail. However, in-depth information about the research work conducted can only be retrieved from the references given.

Chacaltaya Glacier (16°21'S, 68°07'W)

Chacaltaya Glacier is a south-facing cirque glacier located at Nevado Chacaltaya, approximately 20 km northeast of La Paz. In 1998 the surface area of the glacier was approximately 6 hectares, extending from 5360 m to 5140 m above sea level, with a width of 230 m. This glacier is part of the Choqueyapu basin, which supplies part of the water resources of La Paz. Chacaltaya Glacier is directly accessible by road all year around, being used as a ski area during part of the wet season. However, in recent years skiing was discontinued due to lack of sufficient snow. Chacaltaya Peak (5395 m) was climbed by the participants starting from Refugio Chacaltaya (5260 m), see Figs. 3 and 4. This short hike was good training for the afternoon. Huayna Potosí could be seen from the summit. Chacaltaya Glacier was covered by a thin layer of snow. The ski lift infrastructure looked abandoned.

Observations to monitor the evolution of the glacier and to reconstruct past areas and volumes involved (1) direct mass-balance records since 1991; (2) geodetic measurements since 1992; (3) photogrammetric evaluation of aerial photographs taken in 1940, 1963 and 1983; (4) a reconstruction of the LIA maximum using the well-preserved lateral moraines; and (5) a ground penetrating radar (GPR) survey in 1998.

Based on this information the following conclusions were drawn (taken from the references):

(a) The glacier has experienced a major recession since the LIA maximum, losing 89 % of its surface area.

(b) The recession was moderate from 1940 to 1963, with an average mass deficit of 0.221 m w.e.a^{-1}; the recession rate increased to 0.563 w.e.a^{-1} in the period 1963-83.

(c) Since 1983 the glacier has lost 0.963 w.e.a^{-1}. Considering the total volume of ice remaining, determined by high-resolution GPR measurements, and with no change in the present shrinkage rate, the glacier would disappear within 5-10 years, thus endangering the fresh water supply of La Paz.

From Chacaltaya we descended to Milluni Valley and continued further on up-valley, passing by the old miners' graveyard of Milluni, and finally reached Zongo Pass (4770 m) at the foot of Huayna Potosí, see Figure 5. The ice-covered summit of Huayna Potosí is 6088 m high. It was first climbed by R. Dienst and O. Lohse in 1919. Since Huayna Potosí is located just 30 km north of La Paz, the base camp for climbing the mountain can be reached within two hours. The final ascent starts from the high base camp at 5200 m. The climb of Huayna Potosí is not very difficult for experienced mountaineers. Proper altitude acclimatization is of course an essential prerequisite for a successful climb, which normally takes about two days.

However, the participants of the excursion were not expected to climb to the summit. Instead, the group hiked along a footpath through a beautiful high-mountain landscape in order to reach a vantage (vista) point (5200 m) from where Huayna Potosí and Zongo Glacier could be overlooked. We could also see the automatic weather station nearby.

Zongo Glacier (16°15'S, 68°10'W)

In 1995 the glacier was 3 km long and had a surface area of 2.1 km^2. The upper reaches are exposed to the south (Figure 6), whereas the lower section faces east (Figure 7). The maximum and minimum elevations are 6000 and 4890 m a.s.l., respectively. In 2001 the average equilibrium-line altitude (ELA) was at 5250 m. As already indicated previously, tropical glaciers are very sensitive to climate changes because of the peculiar climatic conditions prevailing in the tropics, which cause permanent melting in the ablation zone of glaciers throughout the year due to steady air temperature and constant incident solar radiation.

Since 1991 IRD has been running a long-term monitoring program at Zongo Glacier, which includes the measurement of proglacial stream discharge, (monthly) glacier mass balance, precipitation and other meteorological parameters. For more information please see the references. Glaciologists also studied the impact of El Niño-Southern Oscillation (ENSO) warm events on the local climate and mass balance of Zongo Glacier. The 1997/98 El Niño event was particularly striking at Zongo Glacier. Both a deficit of precipitation and an increase in air temperature caused a strongly negative mass balance of -1960 mm w.e.a^{-1}. It can

be concluded that tropical glaciers in the Andes have been retreating rapidly for some decades because of a combination of both effects, global warming and ENSO warm events.

The return path to the parking area near Laguna Zongo was relatively steep and difficult, at least for the upper part which was running along the crest of the orographic right LIA moraine of Zongo Glacier. The left LIA moraine can be seen in Figure 7. This Figure also shows the tongue of the glacier and its frontal lake.

On the way back to La Paz the group enjoyed panoramic views of Lake Titicaca and La Paz.

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25 March, 2005: Lake Titicaca (La Paz – Lake Titicaca: Copacabana, Sun Island, Moon Island – La Paz)

Figure 9: Basílica Virgen de la Candelaria, Copacabana, Bolivia.

Figure 10: View across Lake Titicaca (3812 m) towards the Cordillera Real.

The Bolivian Andes are composed of the Cordillera Occidental in the west, the Cordillera Oriental in the east, and the Altiplano in between (see Figure 1). The Altiplano is a high plateau that gently dips from north (3800 m) to south (3600 m). The Altiplano comprises Lake Titicaca at the border between Peru and Bolivia, Lake Poopó, which is a salt lake, and the salt flats of Uyuni and Coipasa, present remnants of a former larger lake which covered the Altiplano at the end of the Pleistocene epoch.

Lake Titicaca has a surface area of 8372 km² and is the highest commercially navigable lake in the world at 3812 m above sea level. It has an average depth of 107 m, and a maximum depth of 281 m. More than 25 rivers empty into Lake Titicaca, which has more than 40 islands. Lake Titicaca is fed from rainwater and meltwater from the surrounding mountains. It is drained by the Desaguadero River, which flows south through Bolivia to Lake Poopó. This accounts for less than five percent of the lake's water loss, however, the rest is caused by evaporation as a result of the strong winds and solar radiation. Due to its cultural history, dating back to Inca and Pre-Inca times, and because of its beautiful scenery Lake Titicaca has become an attractive tourist destination.

We left La Paz via El Alto (4082 m) early in the morning heading to Huatajata, which is a small village on the shore of Lake Titicaca. Before boarding the hydrofoil, the fastest means of transportation on Lake Titicaca, we visited the informative local museum. The fast motor boat brought us first to the small town of Copacabana. We then made a short stop on Moon Island (Isla de la Luna), spent lunchtime on Sun Island (Isla del Sol) and finally headed back to Huatajata and La Paz.

Copacabana (20,000 inhabitants) is located at Lake Titicaca in Bolivia near the Peruvian border, and it has a long history dating back more than 3000 years. Today Copacabana is a very important place of pilgrimage for indigenous people and Catholics alike (Figure 9). The Basilica of Our Lady of Copacabana (Basílica Virgen de la Candelaria) hosts a miracle-working Black Madonna. The image of the Virgin Mary (Morena del Lago) was canonized by the Pope in 1925. It should be noted that the well-known Copacabana beach in Rio de Janeiro, Brazil, derived its name from this sacred place. Other places of worship and also the streets leading to the small harbor were crowded with local people, pilgrims, and tourists.

After a visit to the Temple of the Moon on Moon Island, we went to Sun Island, which is one of the largest islands of Lake Titicaca. It is the site of several important Inca ruins and its economy is mainly driven by tourism revenues. The view of Lake Titicaca with the high mountains of the Cordillera Real in the background was rewarding (see Figure 10).

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26-28 March, 2005: Altiplano (La Paz – El Alto – Nevado Sajama – Oruro – Lake Poopó – Meteorite Crater – Salar de Uyuni – Uyuni – La Paz)

Figure 11: Volcano Sajama (6542 m).

Figure 12: Visit to Meteorite Crater.

Figure 13: At the northern entrance of Uyuni salt flats (3650 m) looking towards Volcano Tunupa (5321 m).

Figure 14: Participants of the HMRSC-VIII field excursion at the northern entrance of Salar de Uyuni. At this time the Salar was inundated. The road disappeared in a vast shallow lake.

Figure 15: Railway cemetery of Uyuni.

The longitudinal transect of the Bolivian Altiplano, which began with a visit to Lake Titicaca on the day before was to be continued in southerly direction, ending up in Uyuni. The bus of the Faculty of Geological Sciences of the Mayor de San Andrés University was at our disposal. Néstor Jiménez was the leader of the group, which consisted of 15 persons.

The destination of the first day was the former mining town of Oruro, halfway between La Paz and Uyuni. At Patacamaya, 100 km south of La Paz, a detour was made in westerly direction across the Altiplano. The aim was to get a (road-side) glimpse of the highest mountain of Bolivia, Nevado Sajama (see Figure 11). Sajama is an ice-covered extinct stratovolcano and it is located in Sajama National Park, approximately 20 km from the border to Chile. Nevada Sajama (6542 m) was first climbed by J. Prem and P.

Ghiglione in 1939. Sajama National Park (founded in 1939) is the oldest national park in Bolivia and covers an area of 1000 km2. The park could not be visited due to time constraints. On the way back to Patacamaya, however, we had the opportunity to study very interesting erosional landforms along the road-side and to visit pre-Columbian chullpas (funerary towers) made of adobe. The night was spent in Oruro (2700 m, 250,000 inhabitants). The economic decline of Oruro was triggered by the closing of the tin mines during the last century. Today the Diablada (Carnival) of Oruro is a famous folklore event, which has even been included in the UNESCO world cultural heritage list.

On the next day the excursion was continued towards the south, passing by Laguna Uru Uru and Lago Poopó, which is a shallow and salty lake. At Sevaruyo we left the main road to Uyuni in westerly direction. Halfway to the northern entrance to Salar de Uyuni we stopped at Meteorite Crater, which is a very colorful and scenic place (Figure 12). The final highlight of the excursion to the south of Bolivia was the visit of Salar de Uyuni. We approached Salar de Uyuni near Mount Tunupa (5321 m), which is an extinct volcano, see Figure 13. This prominent volcano is of great mythological importance to local Aymara people. Salar de Uyuni covers an area of approximately 11,000 km² and is the world's largest salt flat (plain). Its mean height is 3650 m above sea level. The crust of salt – the major minerals are halite and gypsum – is between 2 and 7 meters thick. Each year approximately 25,000 tons of salt are extracted. At the time of our visit Salar the Uyuni was flooded by rainwater draining from the surrounding mountains (see Figure 14). The depth of the water varied between 10-30 cm. Since the salt flats are impermeable and have no outlet, the water just stays until it evaporates.

The bus-drive through the vast, shallow lake of salty water was exciting for everybody. It was also challenging for the bus-driver, since navigation is quite difficult without prominent landmarks. At an elevated spot we stopped for a short time. There we could admire salt crystals and enjoy the unique scenery. At sunset we reached Incahuasi Island (Isla de los Pescadores/ Fishermens' Island), which is a small "island" in the Salar. The island is very picturesque because of its giant cactuses. Finally, we safely reached the salt mining village of Colchani in complete darkness. The final destination of today's journey was Uyuni (3670 m, 11,000 inhabitants, transport junction of the region).

On the very last day of the field excursion we visited Uyuni's unique railway cemetery (Cementerio de Trenes). This last visit marked the official end of the HMRSC-VIII field excursions (Figure 15). Most of the participants returned to La Paz (555 km), a few, however, continued their journey to Potosí and Sucre.

The participants of the HMRSC-VIII post-symposium field excursions greatly enjoyed the itinerary and they could thoroughly study one of the most exciting high-mountain environments in the world, the Bolivian Andes.

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Correspondence to:
Viktor Kaufmann
Institute of Remote Sensing and Photogrammetry
Graz University of Technology
Steyrergasse 30,
A-8010 Graz, Austria
e-mail: viktor.kaufmann@tugraz.at