Marmolejo is the southernmost 6,000m plus peak in the world

TO KILL A GLACIER

Air pollution particles are now known to exacerbate glacier melt. Attempting to obtain the highest sample ever collected for analysis in the Chilean Andes, Matt Maynard scaled the 6,108m Marmolejo stratovolcano on the border between Argentina and Chile, and filled his rucksack with snow

Photographs by Matt Maynard and Jon Lawn

Looming over 5,000m summits, comes the pollution bloom of the Santiago metropolis

A pig is grunting around the mountain of boots, rope, carbineers, ice axes, helmets and a seven-day supply of food. It's mid-December. The brilliant Chilean sun is already high above the Maipo Canyon. The shadows from surrounding summits are in retreat across the crashing glacial river. On its bank, the animal snuffles among the standard expedition trappings; stopping at a bright, blue cool box. The pig wanders off and my climbing partner, Jon, and I leave the large cool box in the car to the relief of our *arriero* mule guide.

When he overtook us late that afternoon with his burdened animals on the long climb to base camp, our guide Pablo Aracena, narrowed his eyes. 'People die up there,' he said, chin jutted towards summit. Just last week he helped rescue Brazilians with acute mountain sickness. One had fluid on the brain. 'They didn't look like mountaineers,' he said from his mount. We escape his gaze, pushing surgical gloves, sterilised supermarket bags, thermometer, ruler and spatula deep into day-packs and continued walking.

As we make our 3,500m altitude camp that evening, Aracena waves his arm at the peaks around us – Cortaderas, Yamakawa, Freile, Veleta. A priest administering last rights over the dying glaciers at his feet. 'I was first brought here at five-months-old,' says the *arriero* standing at the camp some ten miles from the dirt road. 'It's climate change that killed them.'

BLACK SMOKING GUN

Of course, Aracena is right. 'All the glaciers in northern, central and southern central Chile are in retreat,' explains Fabrice Lambert – one of the scientists with the project that is the reason we brought the cool box. 'Only in the very southern tip of Patagonia are they more stable.'

Swiss-born Lambert is a climatology professor, and part of the Chilean Centre for Climate and Resilience Research. (CR)2 is a multi-university research group, with both physical and social arms. Lambert works 'upstream,' as he calls it – examining how climate change is affecting Chile's glaciers. Other branches of (CR)2 examine how to adapt to the impact changing river flow will have on hydro projects, agriculture and communities downstream.

In recent years, investigation into glacier and fresh-water loss in the Andes has begun to examine a new variable. Black carbon (combustion particle emissions) had been suspected of exacerbating glacier melt since the 1980s. Yet the difficulty of collecting samples and applying the necessary techniques in remote locations meant the hypothesis had not been tested. American scientist and mountaineer, Carl Schmitt, brought his more economical methods to the Peruvian Andes

Fearing the dizzying effects of mild altitude sickness, Matt practices taking snow samples at lower altitudes to automate the process

Mules were useful in helping transport equipment, but above the 3,500m basecamp, the journey continued on foot

for the first time in 2011. By 2013 the international research group Pollution and its Impact on the South American Cryosphere (PISAC) had also been formed.

While the temperature increase and precipitation decrease directly associated with climate change could account for the majority of glacier reduction, the melting was still greater than Schmitt and PISAC expected. There had to be an additional variable. By sprinkling heat-absorbing dark air pollution particles across glaciers, it was discovered that humans aren't just hatcheting at their snouts. The reality is we are melting down from their surface, along their entire length, into their very core.

THE ELEPHANT IN THE ATMOSPHERE

We sleep two nights at base camp, regaining red blood cells, boiling silty-river water coffee and calculating how to carry all the kit without the help of Aracena and his animals. On the third day we set out to climb the ridge – an 800-metre spine of rock, scree and snow. A jagged staircase provides the only passage out of the valley-head, leading to the high plateau of camp one and the beginning of the summit ridge.

Approaching the 4,350m camp and looking west, our aspect on the ice-smeared slabs of neighbouring Cerro Loma Larga has now improved. Leaning against the scree slope, we gulp in air, examining the rock that separates the peak's three summits. As the morning cumulus clouds clear, a darker more expansive blanket of air emerges. This, however, is no afternoon thunderstorm come to menace climbers. Its effects are much further reaching. Looming over us is the pollution bloom of the Santiago metropolis.

Chile's capital city is the perfect air pollution storm. Each morning – just 80km from the Marmolejo glacier – seven million inhabitants turn the ignition on four million vehicles, while nearby copper smelters fire heavy metals into the atmosphere. In winter, Santiaguinos burn wood for heating; and in summer the higher temperatures and decreased precipitation have increased the prevalence of ash-producing forest fires. The resulting smog is trapped in Santiago by prevailing southwesterly winds pressed against the nearby Andes, and sealed from above by the descending Hadley cell air current.

While levels of atmospheric pollutants consistently exceed World Health Organization annual guidelines for Santiago's low-lying inhabitants, Lambert's (CR)2 team are interested in the extreme reaches of the particles. 'Most of the cities along the Andes depend on meltwater for their fresh water supply,' explains Lambert. Currently three per cent of the nation is covered in ice, and 82 per cent of the continent's glaciers are found in this long, thin country. In recent expeditions to the glaciers in Central Chile, Chilean and international academics have been finding evidence

Tests indicate both black carbon and water-contaminating heavy metals at altitudes up to 5,400m

Throughout their seven days on remote Marmolejo, Matt and Jon encountered no other mountaineers. By the end of the expedition, they heard hallucinations in the wind of other human voices

In Santiago, researchers are now testing the 6,108m snow samples for the presence of black carbon

that urban pollution reaches the Andean summits.

Between 2011 and 2017, Schmitt's American-Peruvian team melted then filtered around 800 snow samples whilst in situ on 15 different Cordillera Blanca peaks in Peru ranging from 4,800m to nearly 6,800m altitude. The results showed a strong positive correlation between a glacier's proximity to a pollution source and its contamination with black carbon. In the central Chilean Andes, Lambert's (CR)2 colleagues, have been filtering back at their lab. To collect their samples they have been donning sterile-boiler suits, boarding helicopters and breathlessly dashing to Santiago's surroundings summits, returning with sterile-shopping bags of snow. Initial results indicate the presence of both black carbon and water-contaminating heavy metals at altitudes up to 5,400m.

On our two-man British expedition, we had neither the necessary manpower to carry a full filter kit, nor the desire to expose ourselves to a 6,000m helicopter ride. Instead we hoped to scale the 6,108m peak under our own power, bag a sample and somehow return through the sweltering heat of Santiago to Lambert's laboratory deep-freezer.

CLIMBING ON THIN ICE

On summit day, we step onto Glacier Marmolejo at 2.17am. Behind our silhouetted-summit, shooting stars fire over Argentinian air space. A 10m rope

connects us – ice crystals spindle down its length in the light breeze, illuminated by our headlamps. The glacier is so frozen that our sharpened crampons leave only tiny scratches. Everything but the sampling kit is left at the 4,900m camp two. The tent soon disappears out of sight.

Over the previous two days we had flirted with the effects of increased altitude. Jon and I had melted snow, moved our camp and tried to automate the snow sampling process in case the summit altitude dizzied our brains. We had also practiced rescuing one another from crevasses. And yet, as we stab now with our axes at the freshly frozen snow – exploring for mountaineer-swallowing cracks – we hit rock. The ice is a pallid veil. This glacier is dying.

Even here, at 5,000m, it appears we are still below the glacier's ELA: the crucial Equilibrium Line Altitude. 'It's a theoretical concept – think about it as the zero-degrees centigrade line,' explains Lambert. 'Above the ELA, the glacier gains mass from precipitation and snow fall. Below this line the glacier is flowing, and melting and it loses mass.'

ELAs have always moved on the world's glaciers. Seasonal temperature changes cause glaciers to ebb and flow, and light absorbing particles, such as dust, have been forever present. Man, however, has now warmed the planet by roughly one degree centigrade, pushing glaciers' ELAs higher. 'At altitude,' Schmitt adds 'this warming is two to three times the value at sea level.'

The scientist estimates that approximately 40 per cent of Andean glaciers in the tropics have already been lost due to rising temperatures. The associated presence of black carbon is increasing the speed of melting by roughly 20 per cent. Schimtt's team have now found the traces of Amazon biomass burning into the high mountains of Peru. 'Black carbon produced in Africa,' he warns, 'has been traced to Brazil, and Chinese emissions are reaching the US.'

By sunrise, only scree separates us from the summit. The glacier ends here at 5,500m. If we'd had a more uphill struggle, there might be hope for Glacier Marmolejo. Steep glaciers are more resilient. As the ELA rises, they lose less mass. But this Chilean glacier gains just 600m altitude over its three-kilometre length. Currently it's melting fast. It's near the point of 'peak water,' where run-off is highest. As precipitation continues to decrease in Central Chile, and the glacier retreats or completely disappears – the flow will slow dramatically. Then it's into uncharted territory.

WALKING THE LINE

A crescent moon shape of spindrift snow separates Chile from Argentina. Terra firma plunges away all on sides and we balance carefully as we follow the ridge. It's -14°C here on the roof of the Andes. Minus 25°C with wind chill. Today the sky is a deep blue, painted thinly over the canvas of outer space. On a cloudy day, a single gust would decide the long final journey of a falling snowflake, to either the eastern Atlantic Ocean, or the Pacific to the west.

Muddled by the enormity, the altitude and a sensation of the peak being eternally distant – we walk past the summit – only realising our error when looking back along the ridge from a lower vantage. Regaining the exposed summit, we steady our drunken steps with an embrace, then go to work with the snow sampling kit.

Out of the wind, I pull sterile gloves over my mitts. I use a ruler and the wide spatula to dig a 10cm-deep trench in the snow. Jon notes the coordinates of the sample and temperature. Next, I excavate the up-slope wall of the trench, scooping two litres of snow into two separate shopping bags. (The (CR)2 team assured us these bags were ideal for the job.) These are then sealed in Zip-lock bags and placed in my rucksack, where an insulating strip separates them from the heat of my back. It takes far longer than we'd like. Eventually we are ready and stagger towards the thicker air of Chile.

Over the next 36 hours we fight to keep the samples frozen. We sleep by day, burying the Zip-locks in snow. When the sun sets, we claw them back from the tightening grip of the ice to continue our descent. Such ad hoc refrigeration tactics work on a micro scale. On a national level, however, the conversation has moved on from mitigation strategies designed to keep glaciers alive. Instead there is now a growing acceptance of the warming we've locked our planet into, as well as the need to adapt to the reduced glacier-water supply that will result.

The Black Carbon in the Andean Cryosphere group is currently measuring black carbon contamination from the Atacama to Patagonia. 'Most of the cities along the Andes depend on meltwater for their fresh water supply,' explains Lambert. 'We need to have a contamination map. Then you can say 'these are the hot spots, these are the areas we can focus on right now.' Only then can decisions about the water security for settlements, agriculture or the feasibility of future hydro projects be accurately made.

Wild with tiredness we reach the car, sling the sample into the cool box and drive it back through the night to Santiago. Its black carbon analysis will play a small part in helping map the fresh water reserves that can be saved in Chile. Its international border coordinates underline an even bigger issue. Worldwide commitment is required in reducing carbon emissions, while still ensuring continued economic growth – especially for developing countries such as Argentina and Chile. The action and consensus required, are mountains left to climb. ●

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Altitude is a major obstacle. Nearer the summit it takes its toll

Around 40 per cent of Andean glaciers in the tropics have already been lost due to rising temperatures

Matt and Jon took to sleeping by day to keep the samples from melting on the descent