The lower part of the September 2012 avalanche: a wide and desolated 'ploughed field' of snow. *(Christian Gobbi)*

windy for half a day and, in our opinion, the wind had not been sufficient to create dangerous accumulations of snow.

This tragic event suggests that every effort to be able to better understand Himalayan avalanches and avoid their consequences is really important. In that respect the work of Nicola Pugno is remarkable: now that we are aware of this model and what it predicts, it will be interesting to verify, and eventually to confirm, Nicola's theoretical deductions through our direct experience.

MICHAEL S. REIDY

Coming Down

or: How Mountaineering Changed Science

John Tyndall as a young man in 1857, the year he first climbed in the Swiss Alps.

Travellers, like plants, may be divided according to the zones which they reach. In the highest region, the English climber – an animal whose instincts and peculiarities are pretty well-known – is by far the most abundant genus.
– Leslie Stephen, Playground of Europe, 1871

When I first spoke to Dragos Zaharescu, he was peering through a high-powered microscope at the microbial life responsible for eating rocks. A researcher in the Biosphere-2 project at the University of Arizona, he is interested in the first biochemical phase of weathering. His research focuses on extreme high altitudes but his office is at a mere 806m in the middle of the North American desert, far from the alpine rock samples he needed in Europe. That's why we were talking. I was planning a climbing trip to one of the highest peaks in Switzerland.

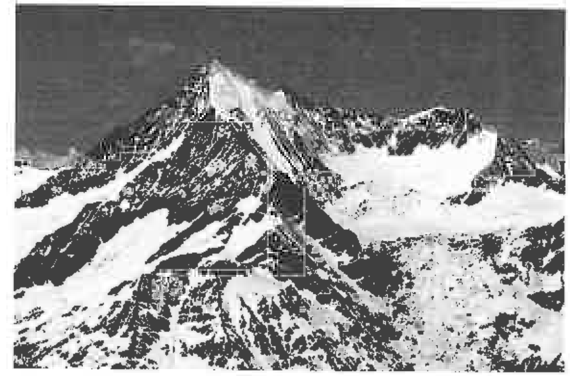
Dragos surmised that the weathering power of the tiny microbes changed

John Tyndall on an ascent of the Lauwinen Thor in August 1860. He often climbed on the rocks while his guides and porters felt safer on the snow couloir. Note the barometer carried by the last porter.
(From John Tyndall, Hours of Exercise in the Alps, London, 1871)

the further one ascended above tree line, but he required rock samples gathered at different heights to test his hypothesis. Gathering observations at varying altitudes had become a significant part of my own historical research. My climbing partner Dennis Duañes and I had our sights on the Weisshorn, our second attempt at the mountain, to follow in the footsteps of the greatest scientist-mountaineer in the history of British climbing, John Tyndall.

Though he didn't know it, Dragos's research had its roots in a vertical orientation to science that took hold in the mid-19th century. That scientific investigations helped spur the development of mountaineering is well known, often forming the introductory chapter to alpine histories. What is less well known is the manner in which alpine climbing helped stimulate a new way of approaching questions in science.

British scientists and explorers had successfully bound the horizontal earth with lines of latitude and longitude, with time zones, railways, and telegraph cables. Yet, by the mid-19th century, naturalists like Joseph Dalton Hooker and Charles Darwin had successfully graphed the vertical realm as well, using different zones of flora and fauna to discern patterns in the distribution of species. A vertical orientation was now directing the science of natural history.



The Weisshorn (4506m). Looking up the east ridge by which Tyndall, Brennen and Wenger made the first ascent on 19 August 1861. This remains the normal route to the summit, a serious AD climb.
(John Cleare/Mountain Camera Picture Library)

Dennis and I were in Switzerland to uncover how Tyndall had used a vertical orientation to similarly transform the physical sciences. We travelled through the distinct vegetation zones of the Matter valley as we headed toward the Weisshornhütte, beginning in the dry grasslands in the small town of Randa (1406m), home to the common rockrose and Carthusian pink. We zigzagged our way through larch and stone pine forests, the upper limit of the sub-alpine vegetation, and then past Tyndall's original bivouac at around 3000m. Only then, amid the scree vegetation of wild thyme, creeping gypsophila, and fairy thimble, did the perfect pyramidal peak of the Weisshorn come into view – stunningly white, and to me, utterly terrifying. Just as Tyndall admitted in his own journal, 'my hopes shrank a little as I inspected it.'

The peak had induced similar fears in the early amateurs and guides who had contemplated climbing it. It was not even attempted until 1859

Dennis Duañes climbing near the summit of the Weisshorn in 2011 to mark the 150th anniversary of the first ascent. *(Michael Reidy)*

when Leslie Stephen made the first tentative attempt. Deep snow and menacing weather forced an early retreat. The next year, C. E. Mathews with guides Melchior Anderegg and Johann Kronig attempted what is now considered the standard route up the east ridge. 'For six mortal hours we toiled up the steep face of the mountain,' Mathews recounted. But at nearly 4300m the hardness of the ice became 'too deadly to be faced' and they turned back. It had been a 19-hour day and Mathews spent the next five confined to a bed in Zermatt without the use of his 'terribly burnt' eyes.

The mountain scorned Tyndall that year as well, but he returned in 1861 determined to be the first to summit what he considered 'the noblest of the Alps'. He was at the height of his climbing prowess. Along with his guide and friend, Johann Joseph Bennen, and porter Ulrich Wegner, he bivouacked the night of 18 August on a platform of overhanging rocks with a spectacular view of the Monte Rosa massif. They woke at 2.30am, brewed coffee, packed their wine and provisions, and were on the glacier by dawn. They reached the bergschrund without rope or incident, and cut steps up a frozen couloir to attain the eastern arête. 'The work was heavy from the first,' Tyndall recalled, 'the bending, twisting, reaching, and drawing up calling upon all the muscles of the frame.'

Once they gained the ridge at approximately 3500m, Tyndall's account becomes more harrowing. The ridge gradually narrowed to a 'pure knife-edge' not exceeding 'the palm of the hand'. It tested Bennen's courage to step across the most exposed sections. 'We reached the opposite rock,' Tyndall said, 'and an earnest smile rippled over Bennen's countenance. He knew that he had done a daring thing.' In his published account, Tyndall focused as much on the science of his mentor, Michael Faraday, as on the

boldness of Bennen. Faraday had demonstrated as early as 1846 how blocks of ice would fuse under intense pressure. As Tyndall explained, Bennen's steps had similarly welded together the fine granules of ice on the knife-edged arête. 'My guide, unaided by any theory, did a thing from which I should have shrunk, though backed by all the theories in the world.'

It was natural for Tyndall to focus on science. He rose to become one of the most outspoken advocates and controversial defenders of science in the 19th century. In this, he was more combative than eloquent, arguing that naturalistic rather than theistic explanations could (and should) account for the workings of nature. He was also the premier defender of what became known as 'agnosticism', a term coined by his early climbing companion, T. H. Huxley. Tyndall's aggressive defence of science and fervent attacks on religion brought him into heated conflict with theologians, philosophers, and other prominent physicists and mountaineers.

Mountaineering was never merely a sport to Tyndall; he conducted significant scientific experiments whenever he climbed. His letters and journals[1], in fact, illuminate how he deliberately formulated most of his research programmes on his ability to climb mountains, consistently performing experiments and comparing observations made at different vertical heights. His attention to the vertical realm significantly changed the scope, method, and direction of his science. His science brought him to the mountains, but the mountains themselves further determined the approach he followed in his researches.

Tyndall was a pioneer discoverer of what we now call the 'greenhouse effect'. His experiments on the contributing gases undertaken in the attic of the Royal Institution and first published in *Philosophical Transactions* [2] in 1861 were a by-product of observations begun during his third ascent of Mont Blanc in 1859 with the chemist Edward Frankland. Together, they set up five observation stations on the mountain as they ascended, performing experiments of all kinds, from burning candles and firing guns to shooting off rockets. They then spent a night on the summit, the first to do so, in order to undertake 22 hours of additional experimentation. His published account offers a mere glimpse of what would become his most enduring scientific accomplishment: 'I hoped to determine the influence of the stratum of air, interposed between the top and bottom of the mountain, upon the solar radiation.' His observations, when perfected in his attic laboratory, represented the first experimental verification that atmospheric gases, particularly water vapour, contribute significantly to the warming of the planet.

This same attention to verticality led to many of his other scientific achievements, including his discovery of a new means of sterilisation (now known as Tyndallisation) and his work on light scattering (known as the Tyndall effect), which explains why the sky is blue. When describing this

1 The Royal Institution houses all of Tyndall's Journals. Everything cited in this paper comes from JT_2_13c.
2 John Tyndall, The Bakerian Lecture, 'On the Absorption and Radiation of Heat by Gases and Vapours, and on the Physical Connexion of Radiation, Absorption, and Conduction', *Philosophical Transactions of the Royal Society of London*, Vol. 151 (London, 1861).

Above and Below: Michael Reidy collecting rock samples near the summit of the Weisshorn. *(Dennis Duañes)*

work in his article 'On the Scientific Use of the Imagination'[3], first published in his *Fragments of Science* in 1871, he explicitly noted the visual imagery that led to his discoveries: 'Now our atmosphere changes continually in density from top to bottom. It will help our conceptions if we regard it as made up of a series of thin concentric layers, or shells of air.' Like his naturalist friends who were actively zoning the earth's flora and fauna, Tyndall vertically layered the atmosphere to uncover the physical properties of light. A focus on changing heights pervaded all of his scientific investigations.

It was for this reason, to actively participate in a similar type of science, that Dennis and I were once again staring at the captivating pyramid of the Weisshorn. And it is why we left the Weisshornhütte at 3am under clear, starry skies with not only ice axes and crampons, but also with all the equipment we would need to gather unseen microbes attached to exposed ledges. It was late August and the crevassed glacier offered little resistance. We climbed the rock ridges leading to the eastern arête in total darkness, attaining its sharp crest just as the soft glow of the sun touched the upper reaches of the peak. We huddled with two other groups at the so-called 'breakfast nook' where

3. John Tyndall, *Fragments of Science for Unscientific People: A Series of Detached Essays, Lectures, and Reviews* (New York, D. Appleton and Co., 1871) Chapter Seven is entitled 'On the Scientific Use of the Imagination: A Discourse Delivered Before the British Association at Liverpool, September 16th 1870'.

Tyndall, Bennen, and Wegner had eaten their first and only meal of the day. Though insignificant to me at the time, it was also well above the last source of drinkable water.

In his published account, Tyndall described his ascent as an incessant struggle, 'a constant and direct expedition of force'. The climax of the narrative occurs on the summit, where he is almost apologetic for his lack of attention to science. 'I opened my note-book to make a few observations,' Tyndall recalled in *Hours of Exercise in the Alps*, 'but soon relinquished the attempt. There was something incongruous, if not profane, in allowing the scientific faculty to interfere where silent worship seemed the reasonable service.'

Their descent – like most descents – proved to be far more difficult than their ascent. All three were exhausted and severely dehydrated. They had taken 10 hours to summit, most of it after they had depleted their supply of water and wine. Wegner had brought a bottle of champagne in case of success, but thirst had quickly overpowered thoughts of celebration. Tyndall uncorked the champagne early, mixed it with snow, and he and Wegner finished it on the way up. Tyndall recalled that there seemed to be ice and snow everywhere but not a drop to drink.

The three moved in seeming slow motion, hoping to at least reach the glacier before dark. 'We thought at first that our descent would be quick but it was not,' Tyndall wrote in his journal. 'We are all stupid; roused at intervals by the roar of the descending stones which we have tumbled from the crest.' It had been sunny all day, both a blessing and curse. It made the mountain accessible, extending the turn-around time and lessening the anxiety of afternoon storms. But it also turned the upper snow slopes into mush and made several sections of the knife-edged arête too unstable. As the sun swung ever lower, they were forced onto tricky mixed rock and ice below the ridge. 'We are often at a loss and wander in a half bewildered way over the Alp,' recalled Tyndall. Lack of water and energy made it difficult to stay focused and Bennen began making Tyndall nervous. The trusty guide had said almost nothing on the way up, but seemed to comment on almost every step during the descent.

Exactly 150 years later, our experience was eerily similar. By the time Dennis and I reached the summit, most of our water was gone and our dehydrated bodies seemed unimpressed by the majestic alpine cirque spread below our feet. A weakness that began in my legs spread quickly, turning to nausea as it hit my stomach and to a sharp pain as it reached my head. We had yet to collect any rock samples.

Not a cloud had appeared in the sky all day and we struggled with the changing consistency of the ice as we finally turned our attention to gathering samples for our scientific collaborators an ocean away in the deserts of America. I was in charge of gathering the samples; Dennis took control of the GPS and other measurements. An exposed section of rock a few metres below the summit offered easy pickings, but after that it took some ingenuity to find accessible observation points. The samples needed to be dry and undisturbed, which meant collecting well off the direct line of the climb. We were forced to belay each other through deep snow to outcroppings on the exposed precipice on the south side of the ridge.

On reaching an outcrop, we had to carefully dislodge small pieces of rock with our ice-axe, double-bag the samples, register the waypoints on the GPS, record the position and direction of the sun, the time and temperature, and attempt to make videos of the entire process. In the end we collected 18 sets of samples, from the summit at 4506m to well below the tree line at 2152m. Both of us were suffering from altitude, we were becoming increasingly dehydrated, and with gloved hands and queasy stomachs we did not always do the work efficiently or correctly. To paraphrase Tyndall, I was ready to get to a heavier concentric layer, a moister shell of air.

After the last rappel off the east ridge, we found water dripping between rocks a little below the breakfast nook. Our purifying iodine required 30 minutes to be effective; we waited a good five. Tyndall had written about Wegner finally finding water in exactly the same place, but neither Dennis nor I said anything about it. Both of us were ready to rid ourselves of Tyndall, rock samples, and everything to do with science.

I now understand Tyndall's silence on science as he finally stood on the summit. We live in a tightly bound world, and lofty intellectual goals diminish rapidly once one moves vertically into the higher concentric layers. Yet, scientists require data from these hard to reach places, areas of the globe which they often do not have the ability to access.

The technical sophistication of today's science often masks the process and people involved. Take today's glacial studies: while the mass and area of glaciers are measured by remote imaging technology from space, appropriated by both big science and powerful states, the research still requires 'digital terrain data'. As a recent scientific study[4] makes clear, glacier measurements must be made 'at reference sites within each of the major mountain systems worldwide using simple methodologies (index stakes, laser altimetry, repeated mapping)'. To translate, 'digital terrain data' and 'simple methodologies' mean actually setting foot on glaciers and making direct, first-hand observations. It entails climbing up the sides of mountains, much like Tyndall had done, using the climber as the remote sensing technologies.

This is why some of the most interesting glacier research is being pursued by some of the top climbers in the world today. The Everest Extreme Ice Survey, for instance, includes a team led by Conrad Anker, who just last summer installed time-lapse cameras in several locations in the high Himalaya. Beginning this summer in the cordillera of South America, a team that includes members of the American Climber Science Program will be initiating a retro-photography study of the Huascarán National Park, a World Heritage Site in Peru. Groups like Adventurers and Scientists for Conser-

4. R.G. Barry, 'Status of Research on Glaciers and Global Glacier Recession: A Review', *Progress in Physical Geography* 30 (2006), 285-306.

A view of the Weisshorn from the Riffel. *(From John Tyndall, Hours of Exercise)*

vation, a non-profit organisation that links climbers with scientific researchers, are undertaking similar projects in a diverse array of sciences.

Mountaineering has never been simply about climbing, especially so during the 'Golden Age'. Most Victorian mountaineers spoke of their yearning to escape the monotony and drudgery of a mundane, urbanised existence, fearing it had eroded their intellectual vigour. Even Leslie Stephen, whose disdain for science is well known, admitted that mountain ascents offered the 'strong stimulants' needed to reinvigorate his 'sluggish imagination'. This could not be accomplished in the streets or salons of London or even in the lower valleys of Switzerland. It required a flight to the heights. As one critic rather curiously put it in the *Westminster Review* in 1864: 'We must rise now and then, like the whales, to a purer medium.'

Victorian scientist-mountaineers were acutely aware that their ability to climb into the 'purer medium' placed them in a unique position to add significantly to some of the most fundamental research of the day, from the geographical distribution of plants and animals to radiant heat and glacier motion. Mountains enabled researchers to experience nature first hand, to see its laws in action, *in situ*. Here, more than anywhere else, one could experience deep time in the formation of mountains and the carving out of valleys, shallow time in the movement of glaciers, and in a single day travel through multiple vegetation and atmospheric zones. After his first day on the Mer de Glace, Tyndall wrote: 'It is difficult, in words, to convey the force of the evidence which this glacier presents to the observer who *sees* it, it seems in fact like a grand laboratory experiment made by Nature.' In the mountains, a personal laboratory opened for those who could reach it.

Throughout his long career, Tyndall combined his two laboratories - one in his rooms in the Royal Institution, the other, his 'grand laboratory' in the Swiss Alps – using mountaineering metaphors to describe his science, and his scientific expertise and notoriety to popularise the new sport of mountaineering. As successor to Michael Faraday at the Royal Institution, he perhaps accomplished more than anyone else in popularising the amazing advances in science during the Victorian era, including the foundational concepts of thermodynamics, radiant heat, and evolution. Both his popular scientific treatises and exciting mountaineering narratives sold quickly to a voracious public intrigued by both the practice of science and the sport of mountaineering.

Perhaps this is one reason why interest in Tyndall is again on the rise. For example, beginning in 2014, British publishers Pickering & Chatto are to bring out Tyndall's entire personal correspondence, over 7,000 letters in 12 volumes, providing an invaluable resource to historians of mountaineering, sport, and tourism, all rising areas of scholarly interest. More generally, however, the significance of Tyndall's varied interests is gaining traction because of the increasing relevance of his scientific accomplishments. If the planet were not warming, for instance, turning the natural greenhouse effect into global warming, the new climatology centre in Britain, the Tyndall Centre for Climate Change Research, would not bear his name. And if the debates over evolution were not still being fought, his staunch defence of a naturalist worldview would not sound so prescient.

This renewal of Tyndall's significance is further intensifying because of the ongoing connection between science and mountaineering. For scientists like Dragos Zaharescu, the ability to climb to high altitudes is a precious commodity. Studies of pikas or wolverines, ice worms or rare rhododendrons, all require 'boots on the ground' in remote and usually elevated places.

As I walked through Zurich airport, my pack weighted down with rocks, I wondered if it was even legal to be transporting the sides of the Weisshorn back to the deserts of the United States. Dennis joked that we may need to check them through Customs, but I would not have known the exact monetary value to assign them. In a sense, they are priceless. Mountains and microbes were both here long before we were. They will be here long after we depart. This is what is so appealing to Dragos and his colleagues in the Biosphere-2 project. They are attempting to understand the high altitude ecosystem and the plants and animals that thrive there, in part to explain how and why we need to preserve them. Leslie Stephen could not have known that the most abundant species in the highest isotherms was not the English climber. It is the genus *psychrobactor*, those earth-eating microbes Dragos is so intent on studying under his microscope. Their instincts and peculiarities are not well known. We will not attempt to save what we don't understand. To understand we must climb into that thin coating that places such extreme limits on humans and engage with the vertical zoning that was so eloquently imagined by Tyndall more than 150 years ago.