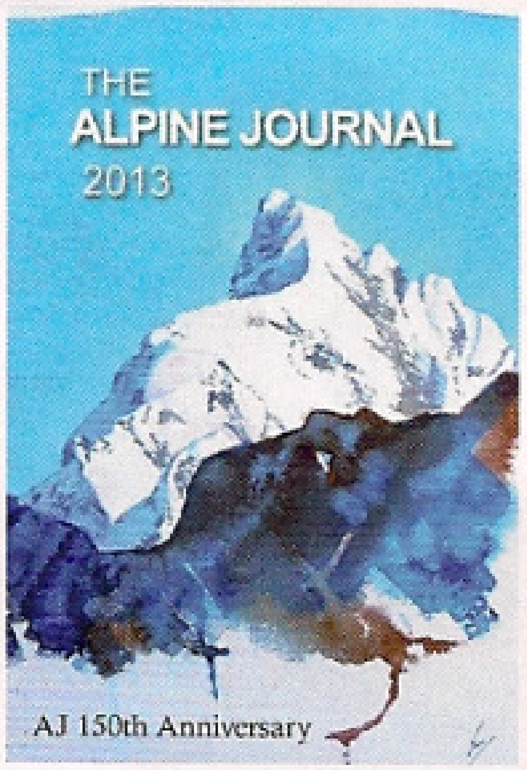


Wise and Fearless

***The Alpine Journal 2013* (The Alpine Club £26)**

This year marks the 150th anniversary of the 'AJ', the oldest mountaineering journal in the world. I suspect that some climbers view the AJ like many other elders of our sport, with plenty of respect but distanced from the cut and thrust of what climbing is today. If so it's a big mistake to make, as this year's *Alpine Journal* is very much alive and kicking, a pulsating mix of cutting-edge alpinism, grassroots exploration, fascinating mountain science and feisty opinion.

The journal's traditional role has been as a record keeper of mountain activities, and the 2013 edition has 70 pages of area notes by the likes of *Climb's* own Lindsay Griffin and Simon Richardson, together with Harish Kapadia and Damien Gildea, all world authorities in their fields. But the AJ is much more than a climbing log, just turn three pages in and you'll find Rick Allen's piece 'The Long Ridge', an utterly gripping account of the first ascent of Nanga Parbat's Mazeno Ridge. Whilst I knew the outcome and basic story, Rick's matter of fact descriptions of the team's continuous trials over 18 days on the mountain added compelling detail to this extraordinary ascent. Team members tumble 300m towards cliffs, winds and snowfall leave them committed and trapped in their tents, and then an epic culmination as Allen and Sandy Allan make a harrowing descent without food, water or shelter, triggering avalanches as they battle for survival. Just their story alone is worth the cover price, but in all there are 17 major expedition accounts from the young vanguard of French alpinism on Kamet, to British legends Fowler and Ramsden on the Prow of Shiva through to more moderate but equally fascinating explorations by skis in Antarctica or by boat through Greenland.

Whilst I'd expected to be captivated by the contemporary mountaineering accounts I was pleasantly surprised by other areas of the journal. Mountaineering history is often a tiresome rehash of far too familiar stories – there is only so much Mallory a man can take. Reginald Macdonald XI could easily have been another of those dry, dusty stories but the AJ brings the past to life with their piece on Whymper's climbing partner dubbed the 'coolest of the cool'. Similarly, the scientific pieces are innovative and relevant, with a detailed piece from three Italian authors on the specific dangers of avalanches on high altitude peaks particularly outstanding. The AJ's book reviews are often authoritative, benefiting from the perspective afforded by an annual publication. AJ editor Stephen Goodwin's combined review of Jim Perrin's two big books this year is as combative and intoxicating as Perrin's own writing. The fact that Goodwin felt able to commission ten paintings from the artist Julian Cooper to celebrate the AJ's 150th birthday shows the Journal's ambition. Long may that ambition and drive continue if it produces books as good as this.

- Ian Parnell

NICOLA PUGNO, GIULIO CARESIO
& SILVIO MONDINELLI

Critical Factors For Himalayan Avalanches

An investigation prompted by the 2012 Manaslu tragedy

124. Looking up the track of the big Manaslu avalanche of 23 September 2012. Photo taken from the site of where most of camp III was deposited by the avalanche. *(Christian Gobbi)*

Science allied to experience… *by Giulio Caresio*

Passion is our great motivator, the irresistible drive that determines most of our steps. I'm thinking of the commitment of alpinists undertaking the most arduous climbs, as well as of my work as editor-in-chief of the Italian magazine *ALP*, and of the strength of all the many people I meet in the mountains whose dedication to their chosen activity stems from loving what they do.

The choice to live and the choice to love are the same thing. This applies to our being in the mountains as well as to the rest of life. Any other choice is to die ahead of our time, to kill our dreams and passions – to give in to one of the worst evils of life: the fear of death.

To love is the way to go further. Surely many of the victims of avalanches, such as the one that swept away Camp III on Manaslu in September 2012[1], knew that truth. Their consciousness and energy reach out to touch us, in spite of our pain, as a precious, pure and bright heritage. The work that forms the subject of this article and scientific effort behind it is devoted to them and their spirit.

To love implies also some risks, but we don't have to allow risk the power to condemn us to immobility. Instead we have to do our best to evaluate, understand and reduce those risks as much as possible.

Last summer, in concerned conversation with Nicola Pugno, one of the leading experts on the phenomena of fracture, the question arose: could the size of the mountain significantly influence its avalanche tendency? The Manaslu tragedy was the trigger to become fully engaged in answering another related question: what help could be given to alpinists by a scientific study on this subject based on the latest knowledge of mechanics? Was it possible to provide alpinists with science-based 'tools' to make a better assessment of avalanche risk on Himalayan expeditions?

Further motivated by his passion as a scientist, Nicola set out to answer these questions, and in October we were able to publish in *ALP* n.285 a first draft of his findings. We really do owe a deep debt of gratitude to Nicola for his incredibly rapid and outstanding scientific work on this important subject.

What follows is a revised and enhanced English version of our special dossier 'Himalayan avalanches'. It includes what seems to us a stunning result: critical conditions for an avalanche or sérac collapse in an 8000m context can be reached with precipitation and accumulations as much as four times less than at 4000m.

This means that mountaineers must be even more on their guard in the Himalaya. The difference in scale factors between the Himalayan and – for example – the Alpine context, means avalanches could occur under conditions that alpinists might judge – according to their experience and related perception – less critical than the circumstances really are.

The conclusion is that we should not transfer Alpine know-how into the Himalayan context without making a 'scale correction' in our evaluations.

Science, it must be acknowledged, produces models of reality and does not reproduce reality itself. It therefore sometimes has limits far greater than those of field experience, which science cannot and does not wish to replace. However it is equally a fact that tools developed by scientists in many situations have revealed and given an understanding of elements and properties that can escape our intuition.

Could this be an occasion when science and experience go ahead, hand in hand, to reduce the risk of Himalayan mountaineering? It is up to scientists and alpinists all over the world, with their direct experience and sensibility, to respond positively to this question.

1 Eleven people died when a massive avalanche hit Camp III at about 6700m on Manaslu (8156m), Nepal, on 23 September 2012. More than 30 people were caught in the pre-dawn slide, most of them still in their tents. One observer estimated the avalanche as being a half-kilometre wide, two metres deep at the fracture and two kilometres long over a vertical height of some 1100m.

An unacknowledged risk at 8000m… *Prof Nicola Pugno*

Risks faced by alpinists at 8000m are considerable and most are well documented. However even the most expert Himalayan mountaineer might be surprised at an additional risk highlighted in research undertaken in the wake of last September's tragedy on Manaslu. I welcome this invitation to record my considerations for the *Alpine Journal* because I consider it my duty not to omit those that might be useful in the future to Himalayan mountaineers; it is certainly not my intent to express judgements of any kind, especially on highly experienced climbers and from my warm office: there could be nothing worse. I therefore refrain from any consideration that is not purely scientific and I express my condolences to the relatives of the victims.

Camp III on Manaslu was situated at about 7000 m altitude. The mountaineer Silvio 'Gnaro' Mondinelli, who survived the tragedy, told me that the avalanche may have been triggered by a falling sérac and that the slope, covered in about 3 metres of snow, was of around 50 degrees. It is true that an avalanche or a collapse of a sérac can take place at both altitudes of 4000m and 8000m, but at 8000m there is an additional risk of which perhaps even mountaineers who habituate the thin air are totally unaware.

The simplest model to calculate the triggering of an avalanche predicts the detachment by friction when the shear stress (sliding force divided by the area on which it acts) on the interface with the weakest layer (typically consisting of snow crystals of larger size) reaches a certain critical value, given by the pressure of the snow multiplied by the friction coefficient. In this model ($\tau = \tau_f$: for details see box), detachment is predicted independently of the amount of accumulated snow and at a slope inclination angle equal or greater than the angle of friction (arctan of the friction coefficient).

A second model predicts detachment when the shear stress, imposed by the accumulation of snow, reaches a critical constant value that is characteristic of the material strength ($\tau = \tau_a = \tau_C$, see box). In this model, the detachment of the avalanche is possible for any slope, as long as there has been a sufficiently abundant amount of precipitation. The least favourable slope, corresponding to the minimum necessary precipitation to cause detachment, occurs at 45 degrees (whereas, mathematically, at 0 and 90 degrees the necessary precipitation to cause detachment tends to infinity). A more evolved third model is based on classical fracture mechanics ($\tau = \tau_F$ [$\Delta a = 0$]).

The unified model ($\tau = \tau_f + \tau_a + \tau_F$) that we propose in the box is based instead on quantized fracture mechanics[1] and a traditional elastic approach[2] and generalises a previous publication on avalanches[3] ($\tau = \tau_a + \tau_F$ [Δa = const.]). This 'universal' model can also be applied for the calculation of the collapse of suspended séracs (and rock avalanches, i.e. landslides). It takes into account friction, adhesion, cohesion and fracture and also has the great advantage (also present in classical fracture mechanics) to be sufficiently realistic as to highlight the size scale of the

The 'universal' model for avalanche triggering and sérac collapse.
by Professor Nicola Pugno

The model assumes the collapse for $\tau = \tau_f + \tau_a + \tau_F$ where:

$$\tau = \rho g H \sin\vartheta \cos\vartheta$$

is the applied shear stress imposed by the weight of the snowfall of depth H and density ρ , on a slope ϑ , where g is the acceleration due to gravity;

$$\tau_f = f\rho g H \cos^2\vartheta$$

is the resistant shear stress of friction, with f the frictional coefficient of the sliding interface;
τ_a is the resistant shear stress of adhesion;

$$\tau_F = \sqrt{\frac{6E/(1-\nu^2)\, G_C\, H \cos\vartheta}{3a^2 + 3a\Delta a + \Delta a^2}}$$

is the resistant shear stress of fracture, with E Young's Modulus and ν the Poisson's ratio of the snow, G_C fracture energy per unit area of the sliding interface, a the half-length of the most critical defect and Δa the 'fracture quantum'.

Assuming $\Delta a \neq \Delta a(H)$ (e.g. $\Delta a = 0$ as in classical fracture mechanics) would allow us to solve the quadratic equation of the model in closed form and thus derive the critical snowfall depth $H = H_C(\vartheta)$ as a function of the slope. In our model,

$$\Delta a = \sqrt{\frac{6E/(1-\nu^2)\, G_C\, H \cos\vartheta}{\tau_C}}$$

where $\tau_C = \tau_F\,(a{=}0)$ is the resistant shear stress of cohesion (the equation can be solved iteratively even analytically or numerically). Self-similarity implies $a \propto A$, where A is the height of the mountain; note that geometrically $h = H\cos\vartheta$.

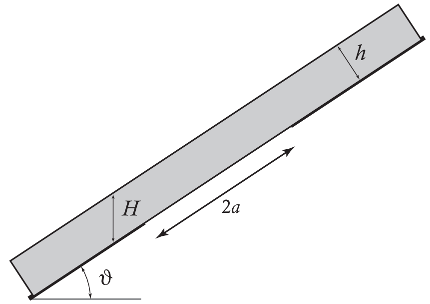
The limiting size-effects are predicted to be $H_C^{(8000)} = H_C^{(4000)}/4$ and $h_C^{(8000)} = h_C^{(4000)}/4$, in contrast to the common perception.

most dangerous defect that generates detachment or collapse.

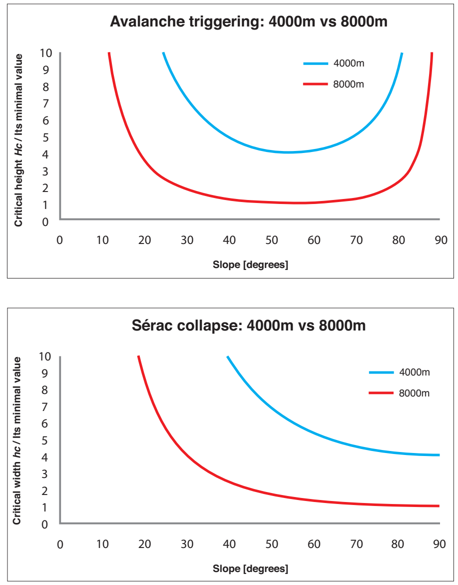
It is not easy to identify in practice this defect (it may be the whole weak interface zone or a super-weak portion of it), let alone its size, but it is reasonable to assume that it is proportional to the size of the slope or the sérac, which in turn are proportional to the height of the mountain. This hypothesis, of so-called 'self similarity', is used in fracture mechanics to explain the observed weakening of structures with their increasing size. In the limiting case of classical fracture mechanics, the critical height of snowfall necessary to cause the detachment of an avalanche (H_C) and the width of the critical part of suspended sérac necessary to cause it to collapse (h_C) are predicted to be inversely proportional to the square of the height of the mountain.

This has a remarkable implication: in order to trigger detachment and collapse at 8000 metres, snowfall and a sérac width of up to only a quarter the amount/size is sufficient compared to those required at 4000m. The least favourable slope for avalanches is around 54 degrees, while for the séracs it is obviously 90 degrees, as can be seen from the accompanying graphs.

Are Himalayan mountaineers aware of this additional risk? Are they aware of the presence of conditions that experience would rightly lead to them considering safe at 4000 metres that could in fact be highly dangerous at 8000m? (See the configurations between the two curves in the graphs.) If they are so aware, then this perception may in part be due to the so-called 'sixth sense' that some alpinists speak about and that has



125. The most critical defect has length $2a$, proportional to the size of the slope and of the sérac, themselves proportional to the height of the mountain. The avalanche is triggered at a critical snowfall depth $H_C(\vartheta)$. For large slopes (e.g. 60-90 degrees) the same model can predict the collapse of a sérac with width of the critical suspended part $h_C(\vartheta)$.



126. Graphs show the limiting size-effects ($\tau = \tau_F\ [\Delta a = 0]$) on the dimensionless critical height of snowfall necessary to cause the detachment of an avalanche (H_C) and on the dimensionless width of the critical part of suspended sérac necessary to cause it to collapse (h_C): 4000m vs 8000m predictions.
Below the red curve the conditions are safe even on an 8000m peak.
Above the blue curve the conditions are unsafe even on a 4000m peak.
The most dangerous zone is that between the two curves: presence of 'abnormal' conditions that are dangerous at 8000m, but which experience would rightly lead to considering safe at 4000m in the Alps

saved them from being swept away by an "abnormal" avalanche or a serac collapse?

Whichever way, the Himalayan mountain climber must take into account the effects of scale when translating his experience at 4000 metres to conditions at 8000 metres. These effects have been the cause of the collapse of ships, bridges and entire buildings. There is no reason to believe that they are not at play in the mountains. They may have played an important role on Manaslu too.

References:
[1] N. Pugno, *Int. J. of Fracture* (2006) **140**, 159-168.
[2] N. Pugno et al. *J. of Applied Mechanics* (2003), **70**, 832-839.
[3] N. Pugno et al., *J. of The Mechanical Behaviour of Materials* (2011) **20**, 107-109.

Witness on Manaslu… ***by*** *Silvio 'Gnaro' Mondinelli*

Sunday 23 September 2012, 4.30 am: I'm sleeping in a tent with my friend Christian Gobbi at Camp III on Manaslu, around 6700m. We hear the loud noise of the avalanche and quickly a huge amount of snow sweeps us down into the valley…

The most impressive thing was that in our sleeping bags, inside the tent, we were hardly pushed down and we really felt powerless. In some moments we had the sensation of floating above the snow, but mostly we felt as if we were enclosed in a sack and being thrown down the mountain. Luckily we stopped after few hundred metres, while other were dragged much further down. We were left without shoes and in light clothing, but unscratched. We had to wait for the daylight to retrieve some gear and start looking for colleagues who stayed with us at high camps.

127. Silvio 'Gnaro' Mondinelli phones home to say he is still alive. *(Christian Gobbi)*

Due to the shock and the need quickly to seek our fellow climbers who had been overwhelmed, we did not think to look at the side of the mountain to determine where exactly the avalanche had come from. Our focus was on the left bank of the avalanche, about 600 m down-slope from us, where we noticed a cluster of tents and people. Most of the Camp III had been dragged into that area.

After few hours, with the help of Sherpas and other alpinists who had climbed up to assist, we were able to find the tent and the bodies of our friend Alberto Magliano and Dawa, his Sherpa. While other rescuers continued to inspect the avalanche debris, Christian and I helped prepare the helipad for the rescue helicopter coming to evacuate the injured victims. We were exhausted, poorly dressed, without crampons, just with boots recovered from the avalanche; we decided to descend quickly to basecamp while the rescue work continued. Going down we realised that the avalanche had reached almost to Camp II and the blast had destroyed so many tents even here, but luckily without victims.

Now I clearly remember: while we were sitting on the snow as dawn approached, we heard and saw a second avalanche that fell on our right side.

I really wonder how such a big avalanche as the first one could have occurred in that situation. Our evaluation about the conditions was good. Some alpinists had slept at Camp III the night before, and other were preparing to ascend to Camp III for the next night. Snow had fallen during the days before, but regularly small avalanches had released the excess

128. A lateral view of the slope of the 2012 avalanche showing the point of the collapse of the sérac – A and the two lower detachment points – B and C that triggered the big avalanche. *(Christian Gobbi)*

129. Scene of the avalanche. This photo, taken in 2011 from around 7000m, shows the slope that avalanched so catastrophically in September 2012. A is camp III, B is camp II. *(Christian Gobbi)*

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

snow from the slope; that's why we felt safe. Moreover it had only been 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.