the usual route and presently caught up with Pavla, who had gone on ahead since she had no need to change. Her boots were reposing peacefully under the cliff.

Two hours later we were at the Aljaž hostel in the Vrata Valley. We made haste, not for fear of being overtaken by darkness, but in order to get up a little warmth.

We gave Torkar, the hut-keeper, quite a scare. The water was pouring off us ; he would have preferred to hang us up to drip ! He produced all his own and his wife's wardrobe and we changed. Like carnival revellers we looked when we met again in the dining-room in appropriately high spirits. The chill damp of our victory over the Škrlatica we dispelled with mulled wine.

Some Physical Characteristics of Snow Avalanches.

By F. S. SMYTHE.

THE question as to whether or not a slope will avalanche is the most vital problem the ski-runner has to face. A considerable amount has been written on the subject, but avalanches are still regarded by the majority of winter visitors to the Alps as haphazard affairs only avoidable by good luck or attention to the warnings on the hotel notice-board. During several seasons' ski-ing experience I have only met one or two ski-runners who possessed any but elementary ideas on the subject of avalanches ; yet avalanches are an exact science and one which to my mind is one of the most fascinating branches of mountain-craft.

Referring to winter-climbs only, avalanches do not affect the mountaineer on foot to nearly the same extent as the ski-runner. At the moment I can only recall the classic disaster resulting in the death of Bennen, February 28, 1864, while accidents to ski-ing parties flock into the mind. The reasons for this are :

1. That comparatively few climb on foot in winter.

2. That ski in themselves are definitely a more dangerous medium of progression than boots or raquettes.

3. That the man on foot necessarily follows a safer route than the man on ski. He instinctively follows the crests of ridges where the snow is usually hard and safe, while the man on ski naturally prefers smoother and more unbroken snow slopes where the risk of avalanches is considerably greater.

I can give some concrete examples to illustrate this thesis.

Once during a bout of spring *Föhn*, when staying at the Darmstädter hut near St. Anton, I spent an afternoon experimenting on the relative safety of boots and ski. Near the hut was a short and steep slope of snow well sodden by the *Föhn*. First of all I traversed it on foot. There was no tendency of the slope to avalanche. Then, returning, I repeated the traverse on ski. The difference was striking. I had barely got half way across when the slope split away at the track of the ski and started to slide. The upper portion of the slope being no longer supported followed the lower immediately. Thus, I was neatly imprisoned in the centre of the avalanche. As previously remarked, the slope was not long enough to present any possible danger, but it was an instructive little experiment for all that.

As regards '3,' the accident near Zürs, January 1, 1927, is a very fair example. I know the place well, and have traversed the Valluga three times. A man climbing the peak on foot would instinctively avoid the steep slope of the Trittkopf, where the accident took place, as a route to the Paziel Glacier. To him, the direct ascent of the terminal moraine would be much less wearying, quite apart from the question of relative safety. If he had mountaineering experience he would doubly avoid the Trittkopf slope, for not only is it long and steep, but its crest is heavily corniched in winter and presents the most obvious avalanche trap. Yet what ski-runner would undertake the trudge on foot up the rocky slope of the terminal moraine carrying his ski in preference to the less fatiguing but dangerous ski-ing route across the Trittkopf slope? This instance is repeated in numberless examples all over the Alps, and I will go so far as to say that, on the whole, the natural route for the ski-runner is very often an unsound one as compared with the natural route of the man on foot or raquettes. I am sure that the majority of avalanche accidents were not so much due to avalanchy conditions as to the following of the incorrect route in the *mountaineering* sense which the employment of ski necessitated. Given two men, one on ski and one on foot, both equally ignorant of snowcraft, the man on foot would instinctively follow the safer route, for the simple reason that a ridge is his natural route, whereas a face is the natural route of the ski-runner.

It is simply and solely the development of ski-ing that has made snowcraft of such vital importance; the man who climbs on foot does not need such exhaustive knowledge because he

is much less likely to detach an avalanche and does not need to venture upon such dangerous routes as the ski-runner.

Guides of olden days, such as Christian Almer, probably did not know as much about snowcraft as the modern ski-runner *ought* to know, but they knew all the snowcraft necessary to enable them to climb safely on foot or raquettes.

Thus it comes about that owing to ski and the unsound routes which their use often entails, the science of avalanche detection has reached—on paper—a higher degree than it would otherwise have done. To say that ski-ing has done much to develop this is undoubtedly true, but ski-runners can hardly claim this with pride, for had it not been for the introduction of ski the number of avalanche accidents—and in justice to the ski-runner, the number of great peaks climbed in winter—would have remained infinitesimal.

Every ski-runner owes a debt of gratitude to the author of 'Alpine Ski-ing at all Heights and Seasons,' and to the Editor of 'Die Gefahren der Alpen,' in both of which works avalanche craft is dealt with very lucidly.

The efforts of the Ski Club of Great Britain to instil snowcraft into ski-runners are also admirable, but the vital point is that this most intricate branch of mountain craft can only be acquired by a long apprenticeship of the mountains in all their moods. However, the idea is excellent and the foundation of a knowledge of snowcraft can be acquired thus.

The science of avalanches is an exact science depending upon definite physical laws, and my only excuse for this paper is to place on record some observations extending over several seasons of winter mountaineering and ski-ing.

It may be of interest to go through the successive stages of avalanches. Snow when it first falls is crystalline. Each flake resembles a number of tiny ice feathers radiating from an apex. If the new snow-fall falls on loose powder snow it quickly becomes consolidated with it, but if it falls on to crusted snow a considerable period may elapse before the two become homogeneous. In both cases, before homogeneity takes place the slope may avalanche of its own volition, or as the result of some outward disturbance such as the cutting effect of a ski track. This homogeneity of the new snow with the old is produced by consolidation. In the case of crusted surface: the numberless crystals of new snow that fall on to it form millions of minute points of contact, but these points of contact are not sufficient to bind the two layers securely together. But soon the new snow begins to settle, and its

weight tends to break the underlying crystals and press the new layer more firmly against the old layer. Sun and frost are the quickest agents of consolidation, but it is a mistake to suppose that fresh winter snow requires these. Consolidation proceeds independently from the constant shrinking of the snow-layer. As everyone knows by pressing two pieces of ice together one can cause them to unite. The same applies here. Pressure is sufficient to unite the numberless little ice crystals on the underside of the upper layer of newly-fallen snow with the old snow beneath.

Wind is another factor that aids consolidation, and one which I have never seen mentioned. It has been stated that no ice can form at over 10,000 ft. in mid winter. This is not quite accurate. Sun may have no influence at all, but wind is an enormous factor. Board hard wind-crust is merely wind-consolidated snow in the first stages of ice. During some recent ascents in the Bernese Oberland some blizzards of great severity were experienced, and afterwards the rock ridges at heights of over 12,000 ft. were plastered in ice consisting of long drawn out ice crystals as much as a foot long and 6 in. in diameter. Nothing but wind pressure could have produced this ice, and the influence of wind pressure on a slope of newly-fallen snow must always exercise a consolidating effect.

Whether or not the newly-fallen snow is wet or dry makes a considerable difference. Wet snow obviously falls at a temperature round about freezing point, and its crystals are less feathery than dry snow. That is to say they are larger and fewer in number. They are like a tree with trimmed branches, whilst dry snow-crystals are of far more complicated construction. The result of this is that there are even less contact points between the two layers with less adhesion and a consequent tendency to avalanche. Owing to the high temperature the two layers cannot unite while the wetness of the new snow acts as a lubricant between them. Directly the temperature falls, however, consolidation takes place with celerity, and not only does the new layer freeze firmly to the old but the slope is now one homogeneous mass safe enough to bear any number of ski-runners.

When snow falls with a wind two different factors enter into the situation. In the first case the snowflakes are blown directly against a slope where they are consolidated by the pressure of the wind into a hard compact cake adhering by pressure to the underlying surface. This is wind-crust and

may vary from the slightest, barely noticeable, crust to a crust in the first stages of ice and hard enough to walk on. Owing to its consolidation by wind pressure to the old layer beneath it *cannot* avalanche.

The other variety of wind-blown snow is more subtle, and forms an avalanche trap, the most difficult and unforeseen of all avalanche forms that the ski-runner has to contend with. It is known as *Schneebrett*[1] or wind-slab, and there still prevails a considerable diversity of opinion as to how it forms. I give my own observations and experiences for what they are worth.

When snow falls with a wind the snowflakes are blown along the surface of the snow or carried through the air until they meet rising ground. The snowflakes are blown up the slope and their delicate crystals are shattered by contact and friction, so that one snowflake may be resolved into a number of minute icy pellets. These are hurried up the slope, becoming even more rounded and icy in the process, and are finally driven over a ridge to fall or be blown downwards on the lee side. In the case of ordinary snowflakes unaffected by this wearing process the flakes are like feathers and have little weight in proportion to the area they occupy. Before consolidation they resemble a mass of feathers or spillikins piled upon one another, and their weight per volume is small. In the case of wind-blown snow, however, its tiny ice pellets occupy but a small volume relative to their weight, and when compacted are of a density many times greater than ordinary snow flakes. As mentioned, these little pellets pour over a ridge and settle in a compact cake on the lee side. The under surface of this cake instead of consisting of spiky feathery crystals, tending to bind it to the old snow-layer, are rounded and smooth. They resemble numberless minute ball-bearings tightly packed together. Now suppose that the consolidating process is still acting on the old snow-layer. It is still shrinking slightly and sinking in the process. The newly formed wind-slab on the other hand is so tightly compacted that it is unable to sink

[1] The term I have heard used for many years. Mr. Smythe, however, informs me that *Windbrett* is now much employed and that several authorities differentiate between *Schneebrett* and *Windbrett*, the former being defined as a 'snow-slab' but not necessarily as a 'wind-slab.' To my mind, no such thing exists as a snow-slab *not* formed by wind. Consequently the two terms are really—or should be—synonymous.—E. L. S.

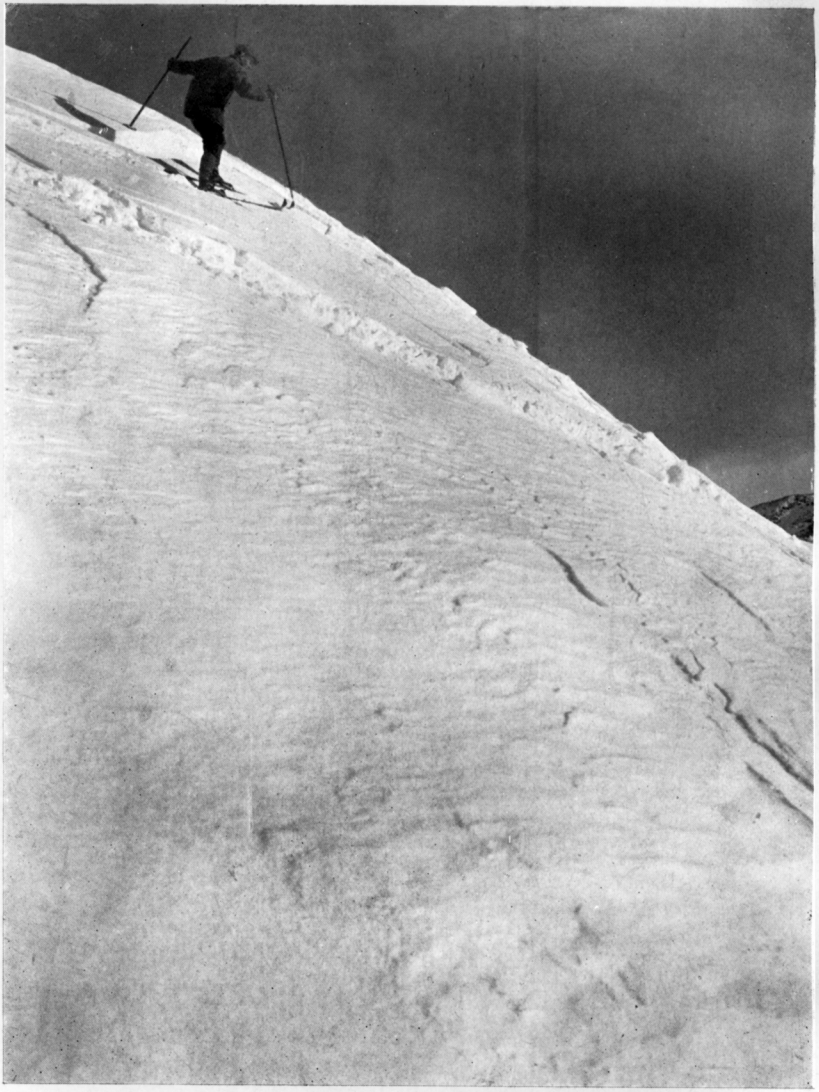

Photo. F. S. Smythe.

THE START OF A "WIND-SLAB" AVALANCHE.

with it. An analogy is the apple dumpling. The apple under the influence of cooking shrinks, leaving a gap between it and the pastry, which, being of a different consistency and tightly compacted, cannot shrink with it. That is precisely the case with the wind-slab. The hard cake of the tightly compacted slab is left with an appreciable gap between it and the old snow-layer with only a few points of support and but little friction to prevent it avalanching. Nevertheless, unlike pastry, the wind-slab is capable of consolidating with the under snow-layer. The process is a slow one and depends entirely on the stage of consolidation of the under layer. If this be ordinary old snow or consolidated wind-slab, the process is a comparatively rapid one. No gap can appear between the two layers, and in the course of a day or so the consolidation of the wind-slab will bind it to the under snow-layer and it will be safe. But where the under snow-layer is itself comparatively new and is still consolidating it is obvious that the process is a much longer one, and it may be days or even weeks before the wind-slab becomes safe, unless it is assisted materially in its consolidation by the sun.

Until consolidation has taken place the danger of an avalanche remains, and the wind-slab, provided it has not fallen of its own volition, lies in wait for the ski-runner or mountaineer. It is a form of avalanche of incalculable effect. Nothing at first sight can appear safer than a slope of snow which may be hard enough to walk upon. But suddenly, with a booming roar, the whole slope splits away, and, aided by the slight caving in effect, breaks up into a mass of hard blocks, sometimes feet thick, which imprison the ski-runner in an iron grasp. It needs but a slope of only 200–300 ft. to prove fatal, and anyone unfortunate enough to be caught in a wind-slab is as likely to be crushed by the weight of the hard snow blocks as suffocated beneath them.

It has been my good fortune never to have been involved accidentally in a wind-slab or any other form of avalanche, but last winter I got a friend to photograph me while I traversed on ski a short slope of obvious wind-slab. This again was an instructive experiment. As in the wet snow avalanche previously mentioned, the slope split, first at the ski track, and then above. It caved in and broke up at the same moment into the characteristic blocks of hard snow. Even on that small slope, which was not more than 50 ft. long, I experienced a feeling of complete helplessness and was irresistibly borne downwards, while the weight of the snow blocks

on the ski twisted my legs and ankles uncomfortably. It is not the object of this paper to describe the appearance of avalanchy snow; that is to be found in the textbooks, but I do not think that any textbook can adequately describe a wind-slab's appearance. It is discoverable only to the experienced eye by the texture of its surface, plus a knowledge of the direction of the wind which formed it, and the lie of the ground. It is also interesting to note that new snow is not necessary to form a wind-slab. Mere wind and blown loose snow is sufficient.

With the exception of the wet snow avalanche, which is too simple and obvious to mention here both in cause and effect, there is only one other main type of avalanche.

The *Staublawine* or powder-snow avalanche is of little danger to the ski-runner, for no one in their senses would venture into a rocky steeply-sided narrow valley after a heavy snowfall. Limestone valleys are especially liable to this form of avalanche. Large quantities of loose snow collect on the large broad sloping terraces, and in the incipient gullies peculiar to limestone. A movement is started and the incoherent snow begins to pour downwards like sugar. New snow has always a considerable amount of air imprisoned in it, and this air is released and flung before the downward pouring snow-stream. At least that is the accepted theory, but it is one which I have always regarded with suspicion. At all events the snow quickly gathers volume and rushes downwards pouring like a cascade over the cliffs, denuding every terrace of its snow and, finally, meeting the less steep lower slopes, shoots outwards across the valley, flinging a furious wind before it, sometimes strong enough to uproot dozens of trees. It is this wind which gives rise to the supposition that the snow contains imprisoned air. It does, but this wind is more probably the displacement of air by the avalanche. A large *Staublawine*, by virtue of its great volume, necessarily displaces more air than a large wet snow avalanche which is of less volume but greater density.

Twenty-three degrees is the angle which has been agreed upon as the *least* angle at which an avalanche can take place, but in the case of a *Staublawine* a much greater angle is required to set snow in motion; probably round about 50°. Thus it is that only slopes of a very high average angle are liable to this avalanche.

There is always something new to be learnt anent snow-craft. This winter our party were turned back from an expedition by a long and steep slope composed of 3 ft. of

perfectly safe and consolidated powdery snow overlying an unsafe, unconsolidated wind-slab. It would be difficult to imagine anything more treacherous and harder to foresee.

As I have said, snowcraft is a fascinating and absorbing study. If only ski-runners would realize this the daily papers would be hard put to it for their usual and tragical winter 'material.'

[Mr. Smythe has requested me to add a few comments to his interesting and instructive paper.

A few points occur to me, and of these by far the most important one seems to be that winter snow conditions have altered, most unquestionably, in the last 30 years. In the periods 1891–2 and 1895–9, during which most of my winter ascents were accomplished, the wind-slab condition appeared to be virtually non-existent. This may have been due to the heavy snowfall of those winters and also to the fact that during all those winters (except 1897–8, when it was exceptionally low), very heavy falls of wettish snow took place in November. The subsequent snow, notably the enormous fall in December–January, 1898–9, fell on already packed and consolidated masses. The first and only wind-slab 'avalanche' that I saw during that period occurred at less than 8000 ft. (early January 1899). The party of three was proceeding along a nearly level *ridge*, less than 10 ft. below the crest, heavily corniched on the far side. The height of the ridge above the 'plain' was not more than 200 ft. I was leading and the crest appeared to turn clean over and fell with a startling report and in great masses, just in front of me, *i.e.* on my side of the crest and *away* from the corniche. The slope on our side of the crest did not exceed 25° while the reverse, or 'corniche' slope, was at about 40°–50°. A snow-storm was raging at the time and the temperature was high. No damage and only a certain amount of alarm was caused.

In those days we waited for at least a fortnight's fine weather before attempting any peaks. This may have been so as to be able to walk comfortably (on raquettes) *on* the snow, but I hope that it was owing to our desire to eliminate any possible avalanche danger. At any rate, in the course of some 30 high ascents of over 12,000 ft., I never *saw* an avalanche of any form or kind.

The South African War then intervened, and I was away from the Alps for 3 years. I returned there in the winter of 1902–3. I saw the first ski tracks at a height of 10,000 ft. and on a glacier! I also saw many avalanches of all kinds, fallen and falling. The dull thud of wind-slabs could be heard on the gentlest, almost level slopes. The tiny crack in the snow surface could be noticed opening out in front of one; sometimes, where the surface was level or nearly so, 20–30 yards ahead. These conditions have prevailed during every winter that I have visited the Alps, 13 in all, some almost snowless, since 1902. The snowfall of 1922–3 was, however,

exceptionally great.[2] The winter of 1924–5, when the December and January snowfall was negligible, was easily the worst. In that season couloirs were especially dangerous; in fact it was only feasible to mount by their rocky banks. The hard snow composing their surface was apt to come away in enormous slabs even at the very base, and this for a solitary individual on boots or raquettes. No wonder that ski-runners have perished by the score during these latter winters.

This winter, although no serious climb was attempted, with an abundant early snow fall, little wind, and a very low temperature, a welcome reversion to old-fashioned winter conditions seems to have prevailed. I noticed no wind-slabs at all.

I fear that I cannot agree altogether with Mr. Smythe when he states that wind-slab 'is discoverable only to the experienced eye by the texture of its surface.' In my experience the eye *cannot* detect any change; it is the *foot* alone that is any guide, *i.e.* that curious feeling of very thin powdery snow resting on hard crust that *may* indicate, to the foot and thence to the mind, the possible lurking danger.[3] But, I do not think this feeling can be communicated through a *ski*. With Mr. Smythe's further statement that wind-slab is discoverable by 'knowledge of the direction of the wind forming it and the lie of the ground,' I concur entirely. Unfortunately, this knowledge is of necessity lacking to the majority of other than *local* mountaineers or ski-runners.—E. L. S.]

I had intended to close my paper as above, but the Editor's comments encourage me to make a few more remarks.

Colonel Strutt's assumption that wind-slabs do not occur during snowy seasons is of great interest. During the season of 1922–3, I ski-ed from November to May in the Arlberg and elsewhere. This was a season of heavy snowfalls, commencing

---

[2] The highest 'peak' that I visited that winter was, however, only the Raxalpe. There was more snow lying in the streets of Munich and Vienna than at, say, Pontresina or Davos, four winters out of five.

[3] This highly precarious state of snow occurred suddenly while mounting the steep snow couloir in the S. face of Les Écrins, July 18, 1927—a very bad summer after a comparatively dry winter. Pierre Blanc, my leader, noticed the danger at once and made a desperately quick spring for the rocky bank. There was no noise and no wind-slab avalanche occurred, but we continued by the (highly glazed) rocks, or, at any rate, holding on to them, right up to the watershed.

Another example of (winter) wind-slab, is the Rottalhorn accident early last summer. The weather had been very bad till near the end of June.

very early, and of little wind ; I did not see one wind-slab, nor do I remember a single avalanche accident in the St. Anton district during that period. Since that season accidents have been very numerous there. It would be instructive to examine statistics, should any be available, of accidents in relation to snowfall. They would reveal, probably, that seasons of little snow are more productive of accidents than seasons of heavy falls. This may sound paradoxical, but is simply due to the fact that during seasons of little snow there is always wind. No doubt this could be verified by meteorological data. At all events, the question opens up a wide field of speculation on the causes of avalanches ; these could best be investigated by Swiss authorities who have more data at hand.

The fact that Colonel Strutt waited until a considerable period had elapsed, after a snowfall, before making his ascents, may of course have accounted to some degree for his not seeing avalanches, but I feel certain that the general principle of *safe* snowy winters holds true. Last winter, 1927–8, when at Pontresina, there was little snow but much wind ; wind-slab formed in many places. And that winter will be remembered as possibly the worst on record for its avalanche casualties.

With regard to the detection of wind-slabs, no doubt surmise is largely responsible. One instinctively suspects the lee slope of a ridge after a blizzard or wind, particularly when consisting of wind-rippled snow. My only definite data on this point are that a slope alternately wind-rippled then of that peculiar smooth shield-like texture [4] for some distance, followed shortly by more wind-ripples is almost invariably wind-slab. It may prove consolidated and safe, but it is wind-slab for all that. Another method of detecting wind-slab is to note the consistency of the snow. If it is all of the same softness or hardness it should be treated as suspicious. In other words, if the ski-runner finds his ski sinking always to the *same* depth, he should suspect wind-slab, but if he finds that the slope is not uniform in its bearing-power, that his ski sink in for a few yards and then run on the surface owing to the slope being composed of alternate breakable and hard crust, then he should realize that the slope is composed of wind-*blown* consolidated snow, incapable of avalanching.

---

[4] In my experience, this shield-like texture is infinitely more dangerous than wind-ripples, probably because these latter consist of *more* compacted snow.—E. L. S.

For this reason I think that it is often possible to detect a wind-slab when on ski. Apart from appearances, there is a curious feeling (on ski) in a wind-slab—a sort of smooth velvety [5] texture impossible to describe and which can be learnt only by experience.

[See also 'A.J.' **23**, 379–86, in which all kinds of avalanches are discussed.]

DR. PACCARD'S 'LOST NARRATIVE.'

An Attempted Reconstruction.

By E. H. STEVENS.

INTRODUCTION.

THE first ascent of Mont Blanc, by Dr. Michel Gabriel Paccard and Jacques Balmat, on August 8, 1786, was from many points of view the most important event in the history of mountaineering. It is a very unfortunate fact that no complete account of their exploit by either of the climbers ever appeared. Dr. **Paccard** undoubtedly intended to publish such an account, and if he had done so, it would have been read, as de Saussure said, from one end of Europe to the other (see note 146). It is actually mentioned by certain bibliographers of the early nineteenth century (see note 125), but it is now generally agreed that it was never published. **Balmat,** however, told his version of the story to Bourrit a few days after the ascent, and **Bourrit** embodied or embroidered it in a pamphlet[1] (Sept. 20, 1786), which went far and wide in France, Switzerland, Germany, and England.[2] In this pamphlet nearly all the credit, both for the discovery of the route which proved the key to the ascent, and for the actual execution of the climb, was attributed to Balmat, while Paccard's part in the enterprise was represented as quite subordinate. To later issues of his pamphlet Bourrit was induced by de Saussure to add a postscript making a sort of apology to Paccard which, however, left his insinuations practically unchanged (see note 146). Paccard, as we shall see, took vigorous steps, in communications to the *Journal*

[5] This is the exact descriptive adjective.—E. L. S.

[1] Printed in full by Dübi, pp. 58–62. An indifferent English translation (which is probably the earliest account of the ascent in English) appeared in *The Scots Magazine* for November 1786, and is reprinted by Montagnier in *A.J.* **25**, 609–12. This translation omits Bourrit's more subjective passages, and does not contain the postscript added, on the prompting of de Saussure, to later editions of the pamphlet (see note 146).

[2] See Montagnier, *A.J.* **25**, 608. Dübi, pp. 63–74.