2.5 Val Pola

The key events hitherto presented are not suspected to have done any *harm to human life* or property. Blackhawk and Köfels occurred in prehistoric times when population in the respective regions – if any – was extremely sparse; and the mountain ranges surrounding Pandemonium Creek, in spite of their beauty, still are remote enough to remain uninhabited and inaccessible to mass tourism. Contrarily thereto, the three following slides – Val Pola, Vaiont, and Huascaran – represent a dramatic crescendo of killed persons and destroyed dwellings. Obviously this tragic score is connected with the fact that, on a world-wide scale, places of residence, under the pressure of a growing population, more and more expand into mountainous areas. How far other reasons may have contributed, will be discussed in Sect. 3.1.

In the context thus evoked geomorphological evidence has to be complemented by a review of the *actions taken by persons* directly or indirectly confronted with dangerous situations.

In the Alps the time between July 15 and 28, 1987, was a period of particularly *heavy precipitation*. In addition, the high temperature (freezing level above 3 500 m) entailed an abnormal runoff from the Alpine glaciers. A great number of flood disasters and gravitational mass movements were consequences of this meteorological coincidence. One of the areas most severely struck was the valley Valtellina (in German publications: “Veltlin”) in northern Italy, near the Swiss border (Notarpietro 1990). To illustrate the general situation, only two of many reports may be cited: “…the storm of July… that… triggered more than 500 mass movements in three left tributary basins of the Adda…” (Crosta 1990, 247). “About 18 people were killed in this region during this time; 10 lives were lost in Tartano when a hotel was struck by a debris flow…” (Costa 1991, 19).

A certain *ambiguity of a dense population* – on the one hand an increased number of threatened persons, on the other hand the existence of a powerful infrastructure assisted by an efficient geological survey – had already shown its character in the mentioned week: no less than about 3 500 people had been evacuated, and there is no doubt that the number of lives thus saved exceeds by far that of victims.

This situation came to a climax when, on July 18 and 19, the possibility of a far larger event had to be faced. It “…was located on the east slope of Mt. Zandila… at the head of Val Pola, a small steep torrent tributary to the Adda River on the west side of the Valtellina. The entire northern mountainside is part of a large prehistoric landslide at the intersection of two major joint sets dipping 45° and 80° into the Adda River valley on an average hillside slope of 32°. Bedrock consists of northward-dipping isoclinal folds of highly fractured and jointed gneiss intruded by gabbro and diorite… Heavy rainfall… caused flooding and debris flows in the Val Pola that eroded the north side of the prehistoric landslide, and formed a debris fan… that dammed the Adda River. A… lake with an estimated volume of 50 000 cubic metres and a maximum depth of 5 metres formed… The lake was partly drained by excavation of an outlet channel…, but new sediment was continually added to the debris fan. On July 25, geologists reported a 600 m long crack at the 2 200 m elevation on the slope of Mt. Zandila adjacent to Val Pola. Over the next two days, the crack increased in width, and rockfalls from the unstable mountainside became more frequent. Between 500 and 600 residences… near the base of the unstable slope were evacuated…” (Costa 1991).
This was the situation which, on the morning of July 28, was followed by the rockslide of Val Pola (Fig. 2.1, 2.27, 2.28, 2.29, 2.30; Cancelli et al. 1990) with an estimated volume of $0.032 - 0.040$ km$^3$ and a total vertical extension of about 1250 metres. In spite of the mentioned successful evacuations in the threatened area, a toll of 27 lives was taken. Seven of these were workers engaged in the excavation of the outlet channel – an extremely risky (not to say heroic) task under the described conditions. This risk had been taken to prevent worse. The other victims, however, could have been saved if an adequate forecast of the slide's motion and its effect upon the lake had been available in time. This is nothing but a statement of facts and by no means intended to blame anybody for not having done the best possible to prevent damage: the persons involved, responsible for hundreds of human lives, had to do their work under extreme stress. Who could imagine, in such instances, that a small accumulation of water, apparently negligible in comparison with the immense mass of rock expected to be detached a kilometre above the valley, would play the most disastrous role in the drama? And there was a tragic irony in the fact that just those courageous workers engaged in the reduction of this accumulation of water were first to perish.

The fatality consisted in the fact that the mass of debris hit the lake at a sufficiently high velocity to entail a flood wave that rapidly travelled upstream. Some general information about waves excited by rockslides will be given in Sect. 7.1. It must, however, be pointed out (and was confirmed by an oral communication of Prof. Vischer, ETH, Zürich) that algorithms for the calculation of waves presented by various authors (e.g. Noda 1970; Vischer 1986) are valid, as a rule, for conditions not fulfilled in the
Fig. 2.28. Val Pola rockslide, general aerial view from the east, few days after event. Involved area stained bright by debris, mud, and water. Note resemblance to Fig. 2.30 and characteristic details: protrusion "Plaz" facing track; newly formed lake at right; intact strip of forest at left. Behind the scar Monte Zandila (2936 m). Low on its slope the shadow of the opposite range that the helicopter is crossing in the light of the raising sun (photo by unknown helicopter pilot having taken part in rescue; by courtesy of the former Swiss Federal Office for Military Airfields)

Fig. 2.29. Val Pola rockslide, aerial view of scar with Monte Zandila in the background. Photo taken few days after event. Note characteristic details: channelling geometry of lateral surfaces, particularly well-developed on the left; beginning erosion by two torrents; the one at right is Pola (photo by unknown helicopter pilot having taken part in rescue; by courtesy of the former Swiss Federal Office for Military Airfields)
Fig. 2.30. Val Pola rockslide. A: scaled down overview of involved area; white spots: damaged villages and hamlets, from north to south: Aquilone, Tirindré, S. Antonio Morignone, Poz, S. Bartolomeo, Morignone, S. Martino Serravalle). Maps (B before, C after event) and longitudinal sections (D, E) along dots-and-dashes lines F-F' and G-G'. Scales of B, C, D, and E are equal. Lines in maps: plain: periphery of involved area; broken: River Adda, torrent Pola. Hatched areas in sections: mass at start; in crossing valley; in ultimate run-up position (circles indicate approximate locations of centre of gravity) (sketch by Erismann)
case of Val Pola. In fact, one of their main assumptions is that the volume of the rock mass be small in comparison with that of the basin into which it plunges. Exactly the opposite was the case: parts of a rock mass hundreds of times larger than the lake literally swept away the water, mixing it with mud and gravel.

Perhaps this unexpected effect would not have happened in such a dramatic manner if the mass had been free to run out in ascending a gentle slope on the eastern side of the valley. But instead there was the massive bedrock protrusion of "Plaz" that, situated in a generally steep slope and right in front of the central axis of the moving mass (Fig. 2.31), acted like the bow of a ship and cut the debris into two lobes. Each lobe ran up on its side of Plaz and fell back, overrunning once more the valley floor and coming to a rest with its distal elements on the western slope again. By the way, as suggested in Fig. 2.32, the particular geometry made the elements turn to run back more or less simultaneously and then move rather side by side than in line. Anyhow, it is probable that the main hit upon the lake occurred when the northern lobe slid back westward and was focused to the lake and the village of Morignone by the concave shape of the adjacent slope.

Two geomorphological facts can be put forward in favour of this hypothesis. On the one hand, the mass, at the beginning of its main descent, was definitely well-channelled by lateral confinements (s. Fig. 2.27, 2.29, 2.30c, 2.33). Thus lateral spreading could not develop on a large scale until it was forced upon the mass by the action of Plaz. In other words, it is not excluded that the mass, in rushing downhill, did not (or only to a small extent) hit the lake. On the other hand, clear marks of a secondary run-up can be observed on the western slope at a height exceeding 1150 m (s. in Fig. 2.30b: protrusion of involved area pointing to the silhouette A). This is exactly the location which
must be expected when considering the mechanism suggested in Fig. 2.32. It is conspicuous that the respective protrusion of the southern lobe, in spite of an approximately equal run-up height of about 1350 m, is far less prominent. This fact points to a substantial difference which very probably was in first instance one of displaced material: speaking in terms of energy, water moves at a lower cost than rock.

Anyhow, in spite of the relatively low velocity of running back there was ample energy available to get as far as can be concluded from erosion and mud marks on the western slope of the valley: initially the wave must have been about 100 m high, and after a distance of 1.3 km some 15–20 m (Govi 1989). And even after a total travel of 2.1 km, when it reached the village Aquilone (not evacuated because of its considerable distance from the slide), it still had the power to damage houses and to kill persons.

The destructive power and extreme mobility of a water-and-mud mixture, even if mobilised by a relatively slow mass, is the first lesson to be learned from Val Pola. The second one refers to the determination of the velocity acquired by the mass of a rockslide.

In Sect. 1.1 the importance of reach (position of the distal elements) and velocity already have been stressed. Both depend in first instance on the available potential energy. This energy is expressed by \( m \Delta z \) where \( m \) is the mass, \( \Delta z \) its vertical displacement, and \( g \) gravitational acceleration.

Obviously the available energy also can be written in terms of kinetic energy. The respective transformation,

\[ v = \sqrt{2g \Delta z} , \]

yields the velocity \( v \) acquired in a free fall over \( \Delta z \). In this formula, resulting directly from Newton's fundamental equations, the mass does not appear since both energies, potential and kinetic, are proportional thereto.
It is a trivial fact that in a rockslide or a rockfall only part of the available energy can assume kinetic form. The rest is transformed – directly or via intermediate states – into heat. In other words: heat is the final effect of all forms of resistance, be it by friction, impact, irreversible deformation or fracturing of material, aerodynamic or hydrodynamic drag, or what else. Thus kinetic energy is nothing but energy not dissipated by resistance, and at the point where the available energy is completely “eaten” by resistance so that no energy can subsist in kinetic form, motion is arrested. This description, though somewhat simplified in details (for instance in case of “recycling” potential energy in running up and down a non-arresting obstacle), gives a clear idea of what essentially happens in a gravitational mass movement. Similar considerations actually yield the energetic basis for Chap. 5 and 6. In the present section the crucial point consists in the fact that motion (and in particular its velocity) directly depends on the energy available beyond that needed to overcome resistance.

In the context of endangering human life easy-to-apply methods for predicting velocity, derived from post-eventum analysis, are a powerful basis for decision-making. And the geomorphological circumstances in the case of Val Pola (Fig. 2.27, 2.28, 2.30), in first instance the topography of its longitudinal section, may be considered as a showpiece for how such analyses should be approached (and perhaps even more how
they not should be approached). In addition, as compared with most other (even re­
cent) events, Val Pola is significant for the existence of maps both for the ante-eventum
and the post-eventum states. So the influence of geometric errors is relatively small. It
is, however, not the scope of a section aimed at geomorphological aspects to describe
methods of this kind in detail. So, as a working hypothesis, the physical background
of the method discussed hereafter will be taken for granted (it is presented and criti­
cally analysed in Sect. 6.2). Here only scarce remarks are made in this respect.

According to Francis and Baker (1977) the maximum velocity $v_{max}$ attained by a mass
between adescent (loss of altitude $\Delta z_1$) and an arresting run-up (gain of altitude $\Delta z_2$)
is obtained from Eq. 2.1 by using

$$\Delta z = \sqrt{(\Delta z_1 \Delta z_2)}$$

(2.2)
to calculate the potential energy remaining after overcoming all effects of resistance.
Anticipating some of the results given under Heading 6.2, this much should be said
about the physical basis of this remarkably elegant (though easy to misuse) method: Eq.
2.2 is correct if (1) the percentage of potential energy transformed into kinetic
energy in descending is equal to the percentage of kinetic energy re-transformed into
potential energy in running up and if (2) no other losses of energy have to be taken
into account (e.g. losses in horizontal motion between descent and run-up).

The event of Val Pola, with only little near-to-horizontal displacement between de­
scent and run-up, seems to fulfil condition of (2) fairly well. And as there is no strin­
gent reason to assume substantially different mechanisms of resistance on the two sides
of the valley (disintegration took place in an early stage so that most of the travel oc­
curred in a more or less unchanged state), also condition of (1) appears to be rather
unproblematic. So it is plausible that several scientists used Eq. 2.1 and 2.2 as a basis
for an estimate of the highest velocity attained at the bottom of the valley (Völk 1989;
Costa 1991). The calculation of $\Delta z_1$ and $\Delta z_2$ was based, however, on the elevations of
the three following points: the bottom of the valley and, respectively, the highest points
of the head scar and the run-up. In doing so, a fundamental physical condition was
violated: any energetic calculation on a coherent body has to be made with respect to
the body's centre of gravity. And at least in two of its relevant positions the mass, in
spite of disintegration and lateral spreading, had to be treated like a coherent body:
when starting, it actually was more or less coherent; and when crossing the valley, it
was longitudinally held together by the driving forces of its (descending) proximal
portion and the braking forces of the (ascending) distal portion. Only in running up
along curved paths on the eastern slope the elements of the mass could have lost con­
tact with each other. But even then its centre of gravity obviously could not reach an
altitude differing from that given by the kinetic energy when crossing the valley mi­

Now the centre of gravity of the mass never was as high as the top of the head scar, it
never was as low as the sole of the valley (not only because of the thickness of the
mass but also because of the distal and proximal ends being higher than the centre),
and, of course, it never could reach the highest position attained by the topmost ele­
ments. So, as can be seen from Fig. 2.30, the differences of altitude are cut down dras­
tically. Instead of $\Delta z_1 = 1150$ m and $\Delta z_2 = 285$ m the respective values are $\Delta z_1 = 850$ m
and $\Delta z_2 = 93$ m, thus reducing the maximum velocity from 106.0 m s$^{-1}$ to 74.3 m s$^{-1}$.

Once more anticipating the results of Sect. 6.2, it can be confirmed that this reduction, in spite of the inherent weak points of the used algorithm, brings down the estimate of velocity to a far more realistic level: Val Pola, without any doubt, was a very fast rockslide, yet there is no evidence in favour of a velocity in the range of 100 m s$^{-1}$ or even 400 km h$^{-1}$ (111 m s$^{-1}$) as claimed by some investigators.

The problem might pass as trivial if there were not a general tendency to overestimate velocity. And the destructive power of an event is, as a rule, proportional to the square of velocity. The fact that the prediction of a catastrophe thus will be rather on the safe side (i.e. an overestimate), is a poor consolation; and it even may turn to the wrong side in calculations used to establish a set of standard parameters as a basis for a more general use. This is by no means an alarmist's fantasy: this is, as reported under Heading 6.2, exactly what happened more than 60 years ago when the first approaches were made to a physically plausible method for the calculation of velocity! And ever since, the wrong results of these early attempts have been re-copied so many times... It is a great satisfaction for an old rockslide-fan to observe how, step by step, a new generation of scientists becomes aware of the difference between the periphery of a mass and its physical centre (Evans et al. 1989, 442, though confined to Körner's model, s. Sect. 6.2; Crosta 1991, 104).

There is a third lesson, somewhat hidden behind the extensive discussion that followed the event of Val Pola. It demonstrates how carefully quantitative information taken from the literature should be considered before using it as an argument in con-

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**Fig. 2.34.** Val Pola rockslide, secondary run-up of water on western slope of Valtellina seen from present valley floor, about 40 m above engulfed Morignone (Fig. 2.30, 2.31, 2.32). Peaks of run-up reach almost another 100 m higher. Though taken eight years after event, photograph clearly shows traces of completely annihilated vegetation (photo by Erismann)
connection with important parameters. It also shows, by the way, that the author of a book about rockslides is not eo ipso exempt from committing such errors.

The rockslide of Val Pola was one of the few events which, as having occurred in the very heart of Europe, were recorded by a considerable number of more or less nearby seismographs. The fact was used by some investigators (e.g. Costa 1991, 25) to back up their assumptions about the attained velocity by referring the distance covered to the duration of a seismic signal and thus obtaining an estimate for the average velocity. In a paper orally presented at the Deutscher Geographentag 1991 and subsequently published, Erismann (1992, 13–15; Kienholz et al. 1993, 306–309) used this information for a somewhat more differentiated analysis, in particular aimed at the necessity of taking into account the centre of gravity and its displacement. Later, when analysing the seismographic records of various Italian (De Simoni et al. 1990) and Swiss laboratories (obtained by courtesy of the Swiss Earthquake Survey at ETH Zürich), some doubts came up with respect to the obtainable accuracy. These doubts were confirmed in an oral discussion with Dr. D. Mayer-Rosa, section leader in the mentioned survey: in spite of the fact that one of the Swiss seismographs is only at a distance of about 30 km from Val Pola, there are at least two problematic points in the interpretation of the records. It is (1) not known how far the mass had been displaced when the first oscillation able to produce an answer in the recorder was emitted; and (2) even

![Fig. 2.35. Val Pola rockslide lake formed after the event, seen from the north (near Aquilone), several months after the slide. At this time it still was far larger than that due to rockfalls preceding the main catastrophe. Sliding surfaces scarcely visible in the background. At right, near the basin separated from the main lake by a tongue, the bright traces of the secondary run-up (Fig. 2.34). In the foreground at left a pumping station provided to lower the water's level (photo by Abele)
over so short a distance the signals, owing to reflections, are transmitted on more than one single path, and the time required to get to the seismograph may strongly depend not only on the length of the path but also on the material. In other words, neither the beginning nor the end of the signal can, at least without an extended mathematical analysis (probably by autocorrelation techniques), unequivocally be correlated with the beginning and the end of the event.

On the whole the Val Pola rockslide, in spite of its tragic aspect, must be considered as an event in which one of the heaviest catastrophes of the century could be avoided by a remarkably efficient hazard management (Costa 1991, 26–36). And this is true not only for the work done under the stress of immediate danger: also in the following time the necessary actions for controlling the massively dammed river (Fig. 2.35), restoring traffic, etc. have been undertaken with admirable vision, skill, and energy.

Not to forget the actual stability of the slope: an extensive, mainly telemetric monitoring network has been installed with microseismic stations, surface and vertical extensometers, piezometers, inclinometers, and, of course, the required processing equipment (I.S.M.E.S. 1990, 4–11). In particular a large protrusion besides the head scar, as being of dubious stability and thus signalling the possibility of a new (though definitely smaller) slide, is observed with due care (Fig. 2.33).