Sharing Knowledge Across the Mediterranean Area
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Volcanic Risk around the Mediterranean[53]

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Abstract. The risks posed by volcanoes are generally less significant than those posed by earthquakes, but they must be studied carefully to prevent their effect: lava flow, pyroclastic flows in explosive eruptions, lahars or mud flows if ice and snow cover the top of the volcano, fall-out of ashes and tsunamis. The case of Vesuvius is examined in more details, as this is the one presenting the highest level of risks in the world.

The previous paper has just shown to us that the Mediterranean was subject to frequent earthquakes. The risk posed by volcanoes is generally less significant than that posed by earthquakes, but from time to time, volcanoes do erupt and, depending on the place and the density of the inhabitants, can provoke sizeable disasters.

I am going to accompany you on a small voyage round the world of volcanic risk, at the end of which I shall speak about the volcano that presents the highest level of risk in the world: Vesuvius, in Italy.

The best-known phenomenon is lava flow, that is, the advance of a high-temperature liquid composed of molten rock: the magma. These lava flows are not very dangerous, apart from one or two exceptional cases such as that of the Nyiragongo volcano in Africa, for example, which, because of the high fluidity of its magma, can produce flows that advance at up to 70–80 km/hour and have therefore caused deaths. Normally, the speed of a lava flow is not great enough to claim victims. The cooling of the flow as it advances increases its viscosity, so the speed of the flow diminishes and there is normally time to save people. The material destruction, on the other hand, cannot be prevented, and lava flows can cause considerable damage.

We have learned to control outflows, particularly in the case of Etna, which is one of the most active volcanoes in the world, with continuous eruptions almost every year, and whose activities mainly consist of lava flows. Two basic techniques have been learned:

– The first technique, shown in these two photos (Figure 1), is diverting a flow by intervening close to the mouth of the eruption, where the magma emerges from the volcano: an artificial channel is installed, then, with the aid of explosives, the lava is rerouted into this artificial channel. Lava is not a Newtonian fluid but a fluid with unusual physical properties, known as a Bingham fluid: the acceleration of gravity is not sufficient to make it move, and if you manage to interrupt the lava flow near the mouth, it ceases. On Etna, this technique has

[53] Transcription from oral in French and translation.

already been successfully applied twice, and we have managed to protect villages in this way.

Figure 1. The control of lava flows. Significant progress achieved at Mt. Etna in the last 20 years. Left: Diversion of the flow into an artificial channel by blasting its levee near the eruptive vent. Right: Deprived of back-thrust, the natural flow front stops. A new flow originates from the diversion site

– The second technique (Figure 2) consists of building dams of earth at the front of the flow with a definite direction, and yields good results. On the left, you can see a transverse dam at the front of the flow which delayed the advance of the lava by a month. On the right, you can see dams built in the direction of the flow, which succeeded perfectly in diverting it in order to protect the buildings you see on the other side of the dam.

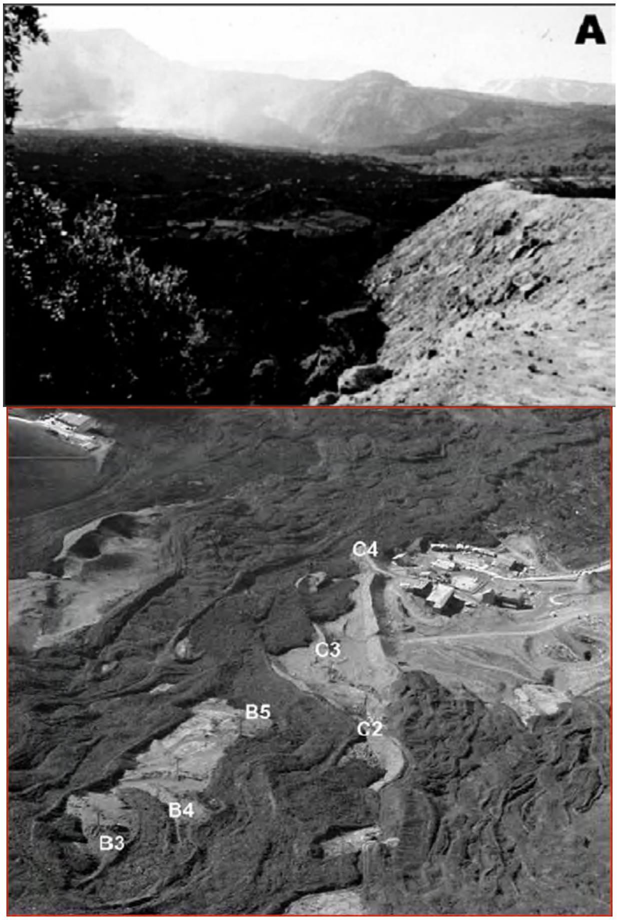

Figure 2. The control of lava flows. Earthern barriers orthogonal or transversal to the flow advancement direction. Left: 1991-92: lava advancement delayed for one month. Right: 2001: lava diverted toward less destructive paths.

We have learned certain techniques, then, to protect ourselves from lava flows.

The real problem posed by volcanic eruptions is when the eruption is of an explosive nature. Unlike the lava flow, which is a continuous stream of liquid, what emerges from the volcano is a cloud of gas rich in fragments of magma. The energy varies greatly, and you can have clouds as high as 50 kms above the volcano or ejections several kilometers high.

Much the most dangerous phenomenon in the explosive activity of volcanoes is the production of pyroclastic flows caused by the cloud's gravitational collapse. These flows advance at a speed that in some cases exceeds 5 kms/hour. They have enormous dynamic pressure and a very high temperature, and because of this an almost total destructive power. Here you see a photo (Figure 3A) of the town of Saint-Pierre in Martinique, almost entirely destroyed in 1902 by a pyroclastic flow, and you can see the form this flow takes when it advances: a cloud of gas laden with pyroclastic fragments (Figure 3C).

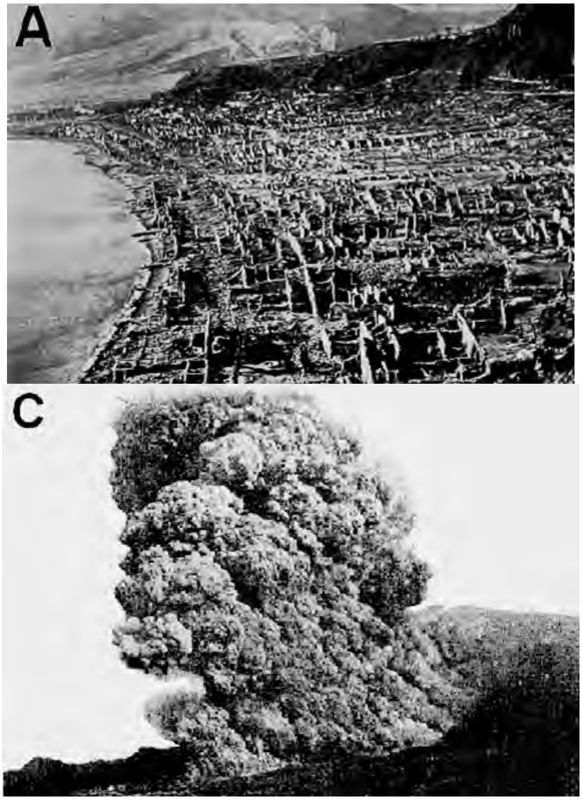

Figure 3. Explosive eruptions. High energy emission of fragmented magma and gas: by far the most destructive. Major disasters produced by:pyroclastic flows, e.g. Mt. Pelée, Martinique, 1902: 29,000 victims

Another very grave danger associated with volcanic activity is mudflow (Figure 4). Several mechanisms can cause mudlows. If there is a layer of ice or permanent glacial snow on the volcano, the eruption can bring about their fusion, and a large quantity of water rushes down the mountainside, causing a flood capable of causing enormous damage. The last example of this, a particularly terrible and catastrophic one, was the Nevado del Ruiz in Colombia (South America), which claimed 25,000 victims in 1985. If there is a lake in the crater of the volcano, the eruption may empty the lake, with, once again, an emission of vast quantities of water that produce very dangerous mudflows. There is a famous example of this in Indonesia, but there is also a risk of this type near Rome, with the Colli Albani volcano (in the Alban Hills) and the lake of Castel Gandolfo—where the pope has his summer residence. It was recently discovered to be an active volcano that had erupted and produced mudflows several times up to the Roman era. The Romans, in the fourth century B.C., dug a tunnel to keep down the level of the lake, thus performing what I believe was the first prevention measure ever taken in the world.

Pinatubo, 1992

Figure 4. Lahars (mud flows): by melting of snow & ice cover, e.g. Nevado del Ruiz, Colombia, 1985: 25,000 victims; by flooding from crater lakes, e.g. Kelut, Indonesia, 1915: 5110 victims; by rain mobilization of loose tephra on steep slopes, e.g. Vesuvius, Italy 1631: 3000 victims (also by p.f.).

Even more frequent is the sweeping along by rain of ashes deposited during an explosive eruption. Explosive eruptions are always accompanied by torrential rainfall, on account of the enormous quantity of water vapour which is ejected upwards over the volcano. There are also ashes that bring down the aggregate of the air's humidity, so there are always heavy rains. Rain sweeps up the loose ashes that have been deposited on the slopes of the volcano, and even on rugged surfaces remote from the volcano, causing these phenomena.

You also have tsunamis that are linked to volcanic eruptions and are not of seismic origin. The causes of these tsunamis are basically of two types: a tsunami can be caused by the entry into the sea of an enormous volume of pyroclastic mudflow; the other possibility is a collapse, say, at the end of a large explosive eruption: an example of this is Santorini in the Mediterranean, to which the destruction of Minoan civilisation is uncertainly attributed, but many other examples exist. Here is a photo (Figure 5) of the island of Stromboli, in southern Italy, where, on 30 December 2002, there was a land-slip, part of it underwater, which provoked a tsunami with a wave 11 meters high. Had it happened in the month of August, the number of victims would have run into the thousands.

Stromboli, 2002

Figure 5. Tsunami: by flank collapse or caldera collapse of volcanic islands; by entrance into the sea of huge volumes of pyroclastic flows. e.g. Santorini, Greece ~1500 b.C.: destruction of Minoan civilization; Tambora, Indonesia, 1815: 10,000 victims (also by p.f.); Krakatau, Indonesia, 1883: 36,000 victims.

The last phenomenon is the fall-out of ashes or fragmentary pyroclastic material. If these accumulate to the point where they exceed the resistance of roofs, the latter collapse. There is also, near the volcano, the ejection of very large blocks, with the damage directly occasioned by this.

These are the phenomena that can occur.

This chart (Figure 6) indicates active volcanoes in the Mediterranean. They are mainly found in two zones: southern Italy, which has the most famous volcanoes in the world, since the classification of types of eruption comes from Italian volcanoes: Etna, Vulcano, Stromboli, Vesuvius, the Phlegraean fields, etc.; and the Aegean arc in Greece, where there are also active volcanoes, the most important of which are Santorini and Nysiros. Paul Tapponnier has just mentioned likewise the posibility that certain areas of France and Germany may yet produce volcanic eruptions.

Figure 6. Volcanic risk in the Mediterranean. Two main areas of active volcanism: Southern Italy (Etna, Vulcano, Stromboli, Vesuvio, Campi Flegrei, etc.) and Aegean Island Arc, Greece (Santorini, Nysiros, etc.). Very large areas can be devastated outside the volcano by tsunami and downwind pyroclastic fallout.

I would remind you that, in addition to the zone around the volcano that can be totally devastated, tsunamis and even fall-out from the ashes carried by the wind can affect much larger areas than the volcano itself.

A number of things can be done to limit the risk.

The first is to anticipate the moment an earthquake will begin. We are in a position to understand, to some extent, that a volcano is about to erupt again. We must put together an emergency plan, therefore, and be able to follow the event up to the moment when the probability of an eruption becomes very high. We must know what to do to save people, and, to be perfectly honest, the only method is to evacuate people from the area.

I am going to set out a few risk measures to adopt for Vesuvius. I am going to talk about Vesuivius, not just because I am Italian and have studied it, but because it is the volcano which presents the highest level of risk in the world. The risk obviously depends on the type of eruption the volcano is able to produce: here, explosive eruptions of considerable energy. But the risk in this case is mainly a result of the almost continual urban growth around the volcano, with an increase in the number of homes which have begun to rise towards the crater (Figure 7). The density of inhabitants would pose problems even in a zone with no seismic or volcanic risk. In some areas near the coast, there are small ports where the concentration of inhabitants per square kilometer is surpassed only by that of Hong-Kong.

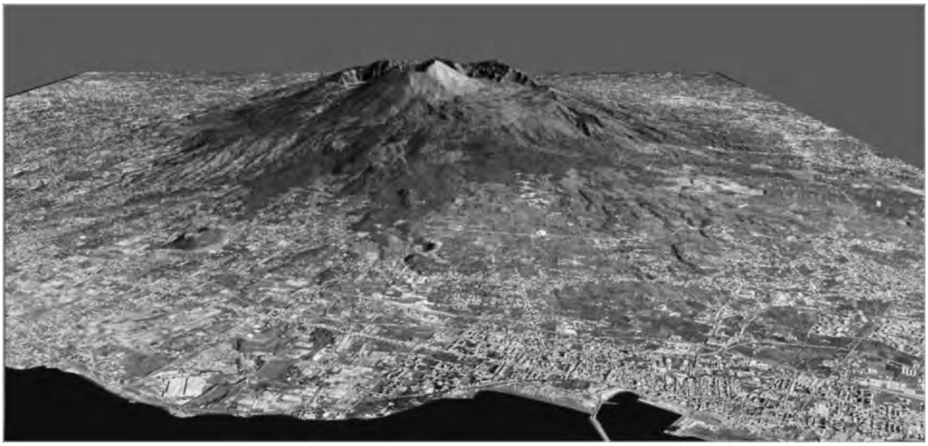

Figure 7. Vesuvius. Because of the explosive character of the expected eruption and the high density of population in hazardous zones, Vesuvius has the highest volcanic risk in the world

The first thing to do when you have to decide the level of risk and what to do is to evaluate the type of eruption that the volcano is able to produce. Now, a volcano like Vesuvius has known different types of eruption in its history. It has had periods of "open behaviour" when activity was persistent, with very frequent eruptions, as is the case with Etna at the moment. The level of explosiveness was on the low side: 3 on the scale of volcanic explosiveness used by volcanologists, which rises as high as 6 to 7, with only small eruptions of magma. This type of activity lasted three centuries and ended in 1944. Since 1944, that is, sixty-one years ago, Vesuvius has been dormant. These dormant periods in the history of the volcano can last centuries, if not thousands of years, but when they are interrupted, it is always by a very violent, high-energy eruption, called Plinian or sub-Plinian. For 60 years, we have been in one of these periods, which is about to be interrupted, we don't know when, by an eruption that will certainly be dangerous. The classic example is the famous Plinian eruption of 79 A.D., but there have been slightly less violent eruptions of this type, and you can see in this picture (Figure 8) the last of these, which dates back to 1631. The dormant periods have lasted as long as 1,000 years in one case, and at the very least 500 years, so they are very long.

Figure 8. Eruptions marking the conduit re-opening after repose periods of variable duration are explosive, of variable intensity, usually with a main plinian (79 A.D.) or subplinian (472 and 1631) phase (sustained and then collapsing column) and initial and late phreatomagmatic phases. Subplinian VEI=4, Vol.=0.1-0.5 km^3; Plinian VEI=5, Vol.=0.5-5 km^3.

In the event of a renewal of eruptive activity in, say, the next ten years, an explosive eruption of a slightly lower eneregy level than the Plinian or sub-Plinian eruption can be expected, but, at all events, of a fairly high level. Very briefly, here is the scenario, with charts of the different risks.

Here is the chart for the fall-out of ashes (Figure 9), which obviously depends on which way the winds are blowing, in this case nearly always East/North-East, East/South-East. The yellow curve, which is the one chosen by the emergency plan, corresponds to a quantity of ash superior to 300 kg per square meter, and you can see from the table that, with ash loads of this order on them, some 20% of roofs will collapse.

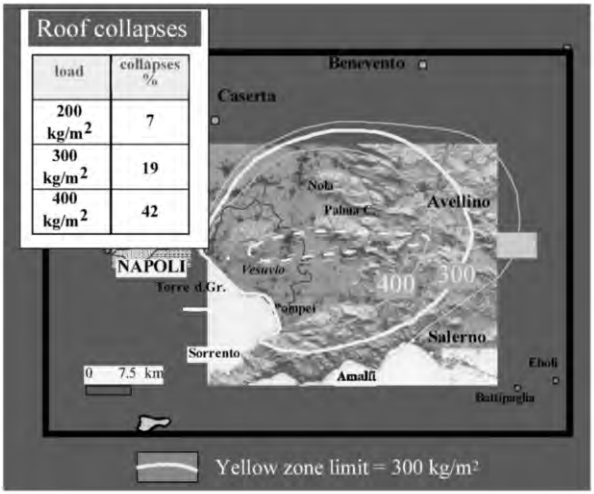

Figure 9. The expected hazards: 1) Tephra fallout

Pyroclastic flows are obviously the most dangerous. By combining a whole series of field studies of the spread of deposits of pyroclastic flows from previous eruptions, and digital simulation, with the aid of physico-digital modelling of eruptions of this type, we are able, after factoring in certain key parameters for the eruption, to estimate the distance that might eventually be covered. All these indicators ultimately lead to this red line, which marks off the zone where the probability of devastation by pyroclastic flows is high (Figure 10). Needless to say, the segmentation is an administrative boundary, marking off the communes around Vesuvius.

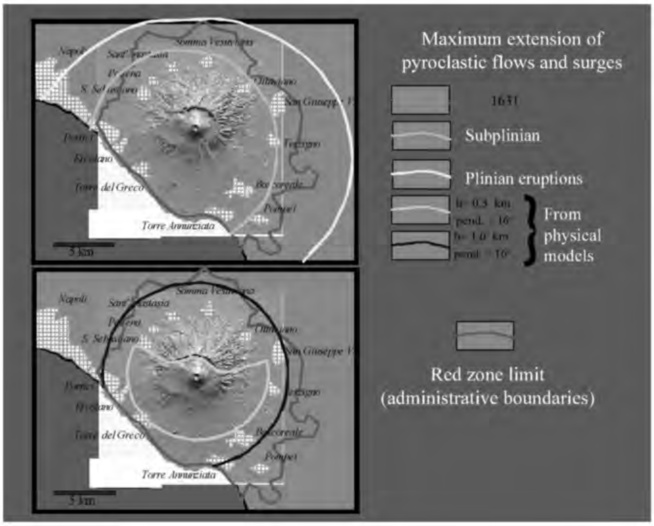

Figure 10. The expected hazards: 2) Pyroclastic flows. Red zone = area exposed to p.f. hazard.

Here (Figure 11), on the right, is an example of digital simulation of pyroclastic flow. The first picture corresponds to 20 seconds after the cloud formation which will generate the pyroclastic flow, and the last picture to 300 seconds or 5 minutes. As you can see, the entire volcano all the way down to the sea is totally affected by the pyroclastic flows in the space of 5 minutes. They are very fast-moving phenomena, then. The whole zone around the volcano will be overrun, devastated and destroyed by the pyroclastic flows in a few minutes after the formation of the phenomenon. This obviously leaves no time to make the population safe once the eruption has begun. To save people, therefore, they must all be evacuated from the zone exposed to the risk before the eruption has begun.

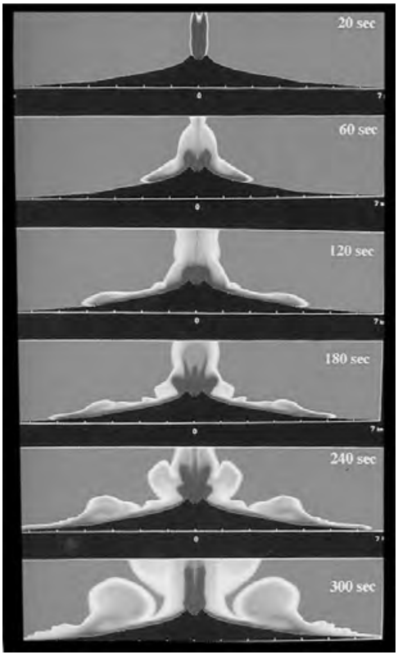

Figure 11. The expected hazards: 2) Pyroclastic flows. Column collapse scenarios obtained by numerical simulation contribute to identify the Red Zone. In a few minutes after column collapse the Red Zone will be devastated. Population living within it must be evacuated before the eruption onset.

Another serious problem is the risk of mudflows. You can see here, on another chart (Figure 12), that the problem is clearly situated on the volcanic edifice, on the cone of Vesuvius; but it doesn't matter, since this is the same zone that will be affected by the pyroclastic flows. You cannot die twice, so only one of these problems needs to be dealt with. But you can see that, given the special direction of the wind in the area of Vesuvius, even people some distance away will be in the danger zone: accumulations of ash, swept along by rain, can generate mudflows even in zones at some distance from the volcano. These people must also be dealt with and saved.

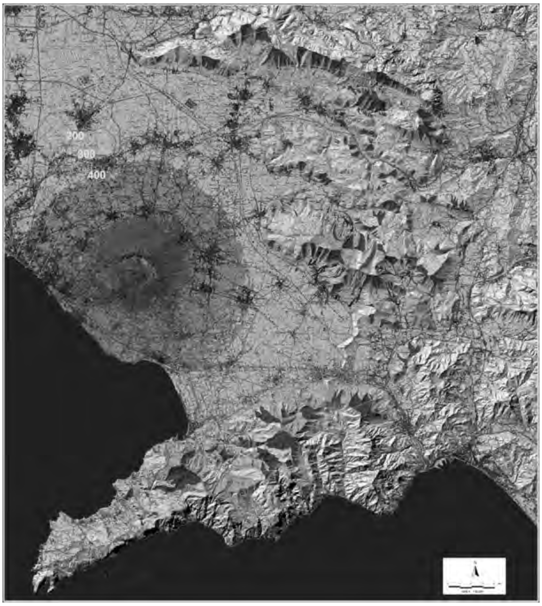

Figure 12. The expected hazards: 3) Lahar (mud flows). Zones exposed to lahar hazard are the volcanic edifice (same zone exposed to p.f.) and all downwind steep slopes interested by tephra fallout

The results are the following. Three zones are defined:

- in the red zone, the zone exposed to the risk of pyroclastic flows, 551,000 people are currently living, that is, more than half a million people, all of whom have to be evacuated before the eruption begins;
- in the yellow zone, the zone exposed to the risk of fall-outs of ash, more than a million people live. Only a fraction of these people (100,000 to 150,000) will be concerned, depending on the direction of the wind. They don't need to be evacuated beforehand, for there is no immediate danger—what's more, it couldn't be done, since nobody can know exactly what direction the wind will be blowing in at the moment of the eruption. They will have to be evacuated at the start of the eruption, when the direction of the wind is known;
- last but not least, in the blue zone, the zone exposed to the risk of mudflows and even alluvions, 181,000 people live. Between 20% and 40% of the inhabitants may be affected, depending on the direction of the wind.

More than 500,000 people to evacuate before the beginning of the eruption… What is to be done? Where can they be put? How can they be taken care of?

The emergency plan for Vesuvius (Figure 13) provides for what is called a twinning chart between the different regions of Italy and the different cities, towns and communes situated around the volcano. Each region has to take charge of one of these towns. For example, Tuscany, the region I come from, has to take charge of the town of Ercolano, which numbers 60,000 inhabitants. The host region must look after everything: housing and food, but also schooling and all social questions. The aim of the plan is to maintain the unity of the administration which is to be evacuated, together with its administrators, teachers and doctors, in order to try and keep down, as much as possible, the number of difficulties you are faced with in a disaster of this kind. People living in the yellow zone (ash fall-out) and the blue zone (mudflows) will be evacuated after the start of the eruption and will be shared out in Campania itself.

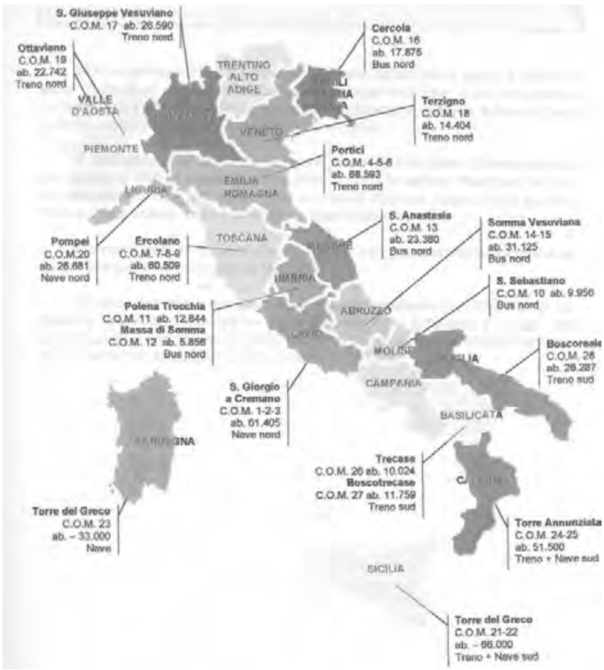

Figure 13. The Vesuvius emergency plan. Residents of each municipality of the Red Zone will be transferred in one Italian Region and hosted so to maintain as far as possible their links (administration, school, health care). A twinning agreement has been signed by all Regions and the National Government. Drilling exercises are regularly carried out involving 1000-2000 students and their families in order to improve links with the hosting communities. People evacuated from the Yellow and Blue Zones will be hosted in Campania Region.

We are able, to some extent, to anticipate the eruption, or at least to realise that the volcano is beginning to change. In a case like Vesuvius, we are dealing with a crater with a narrow throat and, at a certain depth, the magma. Studies of seismic thermographics have been made, for example, which have sought to establish at what depth the magma is to be found. At all events, before the eruption, this magma has to make a journey to the surface, and the eruption begins when it has reached the surface. This journey is accompanied by a whole series of phenomena: earthquakes which produce fractures along which the magma rises; a pressure that builds up at depth with a highly characteristic deformation and upheaval of the soil, gases which leak out. Variations in the chemical and isotopic composition and fluctuations in heat are observed; the rising up of the magma, a substance that has a different density to rock, penetrates at a high temperature, modifiying all the earth's physical fields: gravimetric, magnetic, electric. So if a volcano is monitored properly, if all these parameters are measured, we have a good chance of anticipating the eruption.

The problem is, though, that you have 500,000 people to evacuate before the start of the eruption, and no room for error. If you make a decision too soon, evacuate millions of people and the eruption doesn't occur, it will be an economic disaster. If, on the other hand, to avoid a false alarm, you wait too long, there is a risk that the eruption will begin while there are still people in the danger zones. It really is a very difficult problem to handle.

By way of conclusion, in seismic zones—or in most seismic zones, at least—if you are right on top of the fault, as Paul Tapponnier has shown in certain photos, you can try to protect yourself by putting up seismo-resistant buildings. But for some volcanic phenomena there is really nothing to be done. Buildings that can withstand pyroclastic flows, at a reasonable cost, have not yet been invented.

The only way to reduce the risk where Vesuvius is concerned is to lower the density of the population who live in danger zones. A few years ago, the region of Campania launched a very important programme, with an investment of more than 700 million euros, the aim of which is to lower by at least 35,000 the number of residents in the red zone. There are a whole series of aids allocated to families to enable them to buy a house outside the danger zone; there are also public housing programmes aimed at less affluent populations, again outside the zone at risk. There is also a commitment, which didn't exist before, to combatting improper constructions. I think that some good will come from the fact that, ever since the plan was approved, there has been a great deal of discussion among civil servants and others. Until very recently, nobody wanted to hear about the risk posed by Vesuvius; but now that Vesuvius is an active volcano with a high level of risk, it has entered popular consciousness. This awareness of the risk is an achievement in itself.

Y. Lancelot — The fact that Italy has managed to make a considerable effort, particularly with regard to building and evacuation plans, is quite remarkable when one thinks of the housing pressures in the countries of southern Europe, especially in Italy. One can't help comparing this with what has happened in Louisiana and Alabama, etc. We see that risk exists because populations are settled in places they shouldn't be settled in—they may not necessarily have any choice—and that the big problem is evacuation, with the extraordinary logistics it entails. And we see that if this preparation continues in Italy, they may succeed in reducing the number of victims. Unfortunately, I think there will be a lot of victims all the same.

I am going to hand over now to Jean Virieux, who teaches at the University of Nice Sophia-Antipolis and has taken part in the first underwater seismic instrumentations off the French Riviera.

You have seen the appalling hurricanes that have just occurred, and, above all, the incredible number of victims; you have seen the evacuation of Louisiana, where there was a highway completely blocked and where the opposite lane hadn't been opened—I don't know why—and so people were in an appalling situation.

This clearly shows that it's a problem for which it ought to be possible for norms of civil protection around the Mediterranean to be put in place. This applies both to earthquakes and volcanism. I think that Franco Barberi has clearly shown that, in the case of volcanism, we have a few days, perhaps two or three, in which to do the work; if people are warned at once, if they know there are plans, they will know where they stand.

In the case of seismology, obviously an earthquake has very different effects, but here, too, we need to think about problems of evacuation and emergency aid, which for the moment are not necessarily the most highly developed. Volcanism also causes earthquakes: in Martinique, for example, we know that we will certainly have another earthquake in a short time, perhaps without a volcanic eruption, moreover, and special earthquake-resistant building construction, which costs 20% to 25% more than normal construction, is absolutely not applied.

In the countries around the Mediterranean, particularly in North Africa, I don't know if right now in the region of Al Asnam or the region of Al Hoceima earthquake-resistant building construction is strictly applied. At any rate, it's a point that needs to be stressed, and if one has recommendations to make, it's that there ought to be international commissions for the Mediterranean within the framework of Euro-Mediterranean programmes to oversee construction, since it is ultimately what causes the greatest damage.