SIMULATING LANDSLIDES OF DIFFERENT COMPLEXITY WITH HEXAGONAL CELLULAR AUTOMATA

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ABSTRACT

The paradigms of acentrism and parallelism that are embedded in the definition of Cellular Automata (CA) can be easily and efficiently applied in the simulation of very complex natural processes like landslides. This permits a phenomenological description that is able to overcome resource computational limits, placed in a classical approach and therefore based on the resolution of differential equation systems.

We present a general frame and the latest developments of a CA based model for the simulation of debris flow type landslides.

Landslides are here viewed as a dynamical system that is subdivided in parts which components evolve exclusively on the basis of “local interactions” in a spatial and temporal discretum, where space is represented by hexagonal cells, which specifications (namely substates) describe the average physical characteristics of the respective area. Such a method permits to start from simple landslides, that can be modeled using few substates and simple local interactions; a more complex landslide can be modeled from the previous model, adding substates and local interactions.

SCIDDICA can be considered to exhibit great flexibility in modeling and simulating debris flows. Furthermore it can be applied in some field of intervention such as: The creation of risk maps also with a statistical approach; the simulation of the possible effects of intervention on flows for stream deviation, introducing data which represent alterations of the original conditions (e.g., the construction of a canal or embankment, occlusion of a mud canal etc.). Examples of practical applications on real events involved: the 1992 reactivation of the Tessina landslide in Italy, the 1984 Ontake volcano debris avalanche in Japan and a first partial application to the landslides occurred in the Sarno area of Campania Region (Italy) in the May of 1998.

1. INTRODUCTION

Generally speaking, a debris/mud flow is physically described by fluid-dynamics equations and can range rheologically from approximately Newtonian liquids to brittle solids [Johnson 1973]. Forecasting the development of a debris/mud flow may involve serious difficulties, when the simulations are based on differential equation methods of solution, since it is extremely arduous to solve the governing flow equations (e.g. the Navier-Stokes equations for viscous fluids) [Sassa 1988].

Developments in computing science, particularly in parallel computing, allowed significantly the extension of the application range of classical methods as well as introducing new methods of computation. Moreover, parallel models showed to be, in some cases, a valid alternative to differential equations in simulating complex phenomena [Toffoli, 1984].

Cellular Automata, represent such an alternative approach for modelling complex natural systems. Certainly, they are able to capture the peculiar characteristics of acentric systems, i.e. systems which evolution can be described by considering the local interactions among their constituent "elementary" parts.

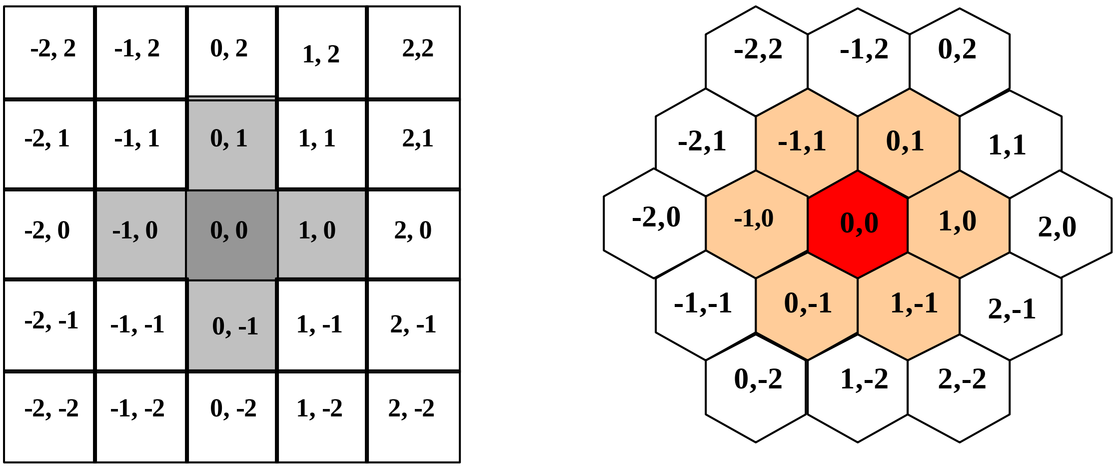

Fig. 1 *Typical CA neighbourhoods: Square (von Neumann) and Hexagonal (Moore equivalent).*

In general, a CA can be intuitively considered as a three- or two-dimensional space (the cellular space), partitioned into cells of uniform size (e.g., cubic, square or regular hexagonal cells). Each cell embeds an identical finite automaton (fa), which states identify the properties of the portion of space corresponding to the cell which are believed "significant" in assessing the evolution of the phenomenon. The input for each fa, is given by the states of the finite automata in the neighbouring cells - where neighbourhood conditions are determined by a pattern invariant in time and constant over the cells. *Fig.1* shows two typical neighbourhoods for a square and hexagonal regular grid CA, respectively the von Neumann and Moore neighbourhoods. At time t=0, each fa is in an "arbitrary" state (i.e. the initial state is defined by the operator, since it represents the initial conditions of the system); CA then evolves by changing, at discrete times and simultaneously, the state of all finite automata, according to rules invariant in time (the so called "transition function", depending on the cell neighbourhood).

In general, CA were mostly developed by adopting a microscopic approach, characterised by a small number of states (not more than a hundred states), aiming at modelling systems through a simple transition function. If we would instead adopt a macroscopic approach, we could be able to consider as far as billion of states and, consequently, a more complex transition function. This problem was treated by Di Gregorio & Serra [1999], which devised an empirical method in order to apply CA also to macroscopic complex phenomena; this approach involves a slightly different formal definition of CA, that is very useful for the practical implementation of the models.

SCIDDICA (Simulation through Computational Innovative methods for the Detection of Debris flow path using Interactive Cellular Automata - to be read "'she:ddre:ca", as the acronym was devised to mean "it slides" in Sicilian), is a Cellular Automata model developed in order to simulate the behaviour of landslides that can be typologically defined as "flows" [Cruden & Varnes, 1996]. These are a good application field for CA, as they can be considered in terms of an acentric system.

Early releases of SCIDDICA were first successfully applied to the landslides of Tessina [Avolio et al., 1999a; 1999b; 2000] and Mt. Ontake [Di Gregorio et al., 1999]. Starting from the peculiarities of the selected landslides, the basic model was modified and extended in order to better simulate specific landslide features. The first versions of SCIDDICA were based on a square grid (i.e. "square" cells). However, old experiments done in the same area with a square grid have confirmed the necessity to have a better detail of simulation to avoid spurious symmetries due to the two privileged directions north-south and east-west. The introduction of six flow directions (i.e. the use of hexagonal cells), more than using smaller square cells (rising inevitably the computer elaboration time), has proven to be a good choice to avoid such symmetries.

In the next section, the principal conditions concerning the macroscopic simulation of fluid dynamics for landslides are discussed. The second chapter, after a brief overview on previous attempts of landslide simulation by CA and similar methods, presents the details of the model SCIDDICA. The third section shortly describes early applications of SCIDDICA to Tessina and Mt. Ontake cases. The first attempts of simulating a debris flow [D'Ambrosio et al., 2001], chosen as case of study among the whole phenomena occurred at Sarno in May 1998, are then presented in the end of this section. Some considerations and conclusions are at last given in the last section. Note that problems, concerning data precision, advised us to perform first simulations of a Sarno landslide on a square version [D'Ambrosio et al., 2001], deduced from the hexagonal CA model.

2. THE HEXAGONAL CA MODEL SCIDDICA

We now illustrate the basic concepts of the SCIDDICA model. The first subsection introduces shortly the context of the problem, concerning the modelling and simulation of debris flows, the previous attempted solutions (to our knowledge) in terms of CA or similar models. The second subsection presents the general frame of SCIDDICA, then the third subsection defines the hexagonal SCIDDICA transition function.

2.1 THE PROBLEM OF MODELLING DEBRIS FLOWS

Analytical solutions to the differential equations (e.g. the Navier-Stokes equations) governing debris flows are a hopeless challenge, except for few simple, not realistic, cases.

The possibility to successfully apply numerical methods for the solution of differential equations have been elevated considerably because of the continuous rise of computing power, even if there are still difficulties to obtain high performances in the implementation on parallel computing machines to exploiting the maximum computational power. It must been said that CAs are a particular model that can be easily implemented in parallel computing [Di Gregorio et al., 1996].

Moreover, the complexity of the problem resides both in the difficulty of managing irregular ground topography and in complications of the equations, that must also be able to account for flows that can range, rheologically, from nearly Newtonian fluids to brittle solids by means of water loss.

Some authors proposed CA or CA-like models for landslides of type flow.

Barca et al. [1986, 1987] designed 3-dimensional CA models with a cellular space divided in cubic cells, but computational high complexity and costs did not permit to apply the model to the simulation, except for few cases of small and simple landslides.

Sassa [1988] adopted the numerical method to finite differences for a simplified solution of debris flow equations and applied it to the M. Ontake landslide. Finite differences imply a discrete time and space in a way very similar to CA. Space is tessellated in square cells of size 200 m. His approach well accounts for the physics of the phenomenon, but the simulation suffered because of the dimension of cells (too large to obtain a highly accurate description of the phenomenon), constrained by computational resource limits.

Di Gregorio et al [1994a, 1994b] developed a simple 2-dimensional CA model (first release of SCIDDICA) and validated it by simulating the M. Ontake landslide (cf. section 3.2)

Segre & Deangeli [1995] presented a 3-dimensional numeric model, based on CA, for debris flows. It has strong analogies with CA of type lattice Boltzmann automata [Succi et al., 1991]; empirical flow laws were adopted; flows were obtained using difference equations. The model was validated on the M. XiKou landslide, capturing its main characteristics.

SCIDDICA was further improved, introducing a hexagonal tessellation and correlating empirical parameters of the model to physical ones, and applied again to the M. Ontake landslide [Di Gregorio et al. 1997b; Di Gregorio et al. 1998; Di Gregorio et al. 1999].

Avolio et al. [1999a; 1999b; 2000] applied a modified release of SCIDDICA to the Tessina landslide (cf. section 3.1), also performing a risk analysis for the threatened area.

Malamud & Turcot [2000] presented a very simple CA "sand pile" model to be applied to landslides from a statistical viewpoint in order to forecast the frequency-area distribution of landslides triggered by earthquakes.

Finally, a preliminary square version was developed in order to capture the characteristics of the extremely complex landslides of Sarno [D'Ambrosio et al., 2001].

2.2 THE GENERAL HEXAGONAL MODEL SCIDDICA

The latest hexagonal version of SCIDDICA is a significant extension of the models applied successfully to the landslides of Tessina and Mount Ontake. Such extension involves new substates, new procedures, new parameters because of the landslides of Sarno appear to be a more complex phenomenon, especially for their avalanche effect in soil erosion during the phenomenon evolution.

The hexagonal CA model SCIDDICA is the quintuple

$$SCIDDICA = \langle R, X, Q, P, \sigma \rangle, \text{ where}$$

• $R = \{(x, y) | \; x, y \in \boldsymbol{N}, \; 0 \leq x \leq l_x, \; 0 \leq y \leq l_y\}$ identifies the regular hexagons covering the finite region, where the phenomenon evolves. $\boldsymbol{N}$ is the set of natural numbers.

• X identifies the geometrical pattern of cells (*Fig.2*) which influence any state change of the central cell (the central cell itself and the adjacent cells):

$$\mathbf{X = \{(0,0), (0,1), (0,-1), (1,0), (-1,0), (1,-1), (-1,1)\};}$$

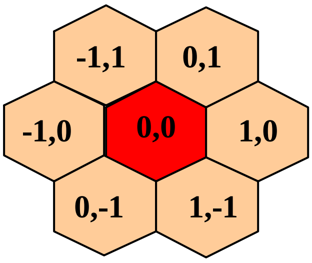

Fig. 2 *Hexagonal neighbourhood.*

• Q is the finite set of states of the fa; it is equal to the Cartesian product of the sets of the considered substates:

$$Q = Q_a \times Q_{th} \times Q_r \times Q_{adh} \times Q_d \times Q_m \times Q_{ms} \times Q_w \times Q_o{}^6 \times Q_{mf}{}^6$$

where:

- Q_a is the cell altitude
- Q_{th} is the thickness of landslide debris
- Q_r is the "run up" height (depends on the potential energy and expresses the height that can be overcome by the debris flow)
- Q_{adh} is the adherence (of flowing debris with the basal surface)
- Q_d is the maximum depth of detrital cover, that can be transformed by erosion in landslide debris (it depends on the type of detrital cover)
- Q_m is the propagation width of the "mobilisation" (i.e. of the change of detrital cover in landslide debris)
- Q_w is the water content in the landslide debris
- Q_o is the debris outflow from the central cell to an adjacent cell (six components)
- Q_{mf} is the "mobilisation flow" from the central cell to an adjacent cell (six components)

The elements of Q_a express the value of the altitude; the elements of Q_{th}, Q_{adh}, and Q_d represent the material quantity inside the cell, expressed as thickness, also the elements of Q are expressed as a length; Q_{ms}, Q_m have a positive integer value; Q_w expresses the water content in terms of thickness because of homogeneity with the expression of the debris values.

• P is the set of the global physical and empirical parameters, which account for the general frame of the model and the physical characteristics of the phenomenon:

$$P=\{p_c, p_t, p_{adh1}, p_{adh2}, p_{adh3}, p_f, p_r, p_{rl}, p_{ma}, p_{miw}, p_{mt}, p_{mdt}, p_{mad}, p_{sol}, p_{swc}, p_{w1}, p_{w2}\}$$

Where:

p_c edge of the cell
p_t temporal correspondence of a step of SCIDDICA
p_{adh1} minimum adherence value
p_{adh2} maximum adherence value
p_{adh3} relates the adherence value to the run up value

p_f friction angle

p_r relaxation rate of debris landslide outflows

p_{rl} run up loss

p_{ma} mobilisation angle

p_{miw} initial value of the Q_m for the mobilised cells at beginning of the simulation

p_{mt} activation threshold of the mobilisation; it is referred to the run up multiplied by debris thickness

p_{mdt} angle threshold, used to determine if the mobilisation can propagate with the same width value of central cell

p_{mad} angle threshold, used to determine if the mobilisation can propagate with the maximum initial width value

p_{sol} water content threshold for the occurrence of debris solidification

p_{swc} initial water content of the detrital cover

p_{w1} water loss parameter in the landslide debris for each step of the CA

p_{w2} debris thickness diminution, as a consequence of water content loss, for each step of the CA

• $\sigma: Q^6 \rightarrow Q$ is the deterministic state transition for the cells in R.

The basic elements of the transition function will be sketched in the next section.

At the beginning of the simulation (t=0) we specify the states of the cells in R, defining the initial configuration of the CA; the initial values of the substates are so initialised as follows:

Q_{th} is zero everywhere except for the detachment area, where the thickness of landslide mass determines its values; of course, all initial values of outflow of landslide debris are zero;

Q_a has the morphology values except for the detachment area, where the thickness of the landslide mass is subtracted from the morphology value;

Q_r has initial values equal to the substate Q_{th};

Q_d has initial values corresponding to the maximum depth of the mantle of detrital cover, which can be eroded;

Q_{adh} has value only in cells, whose Q_{th} is not zero; it is p_{adh1};

Q_m is zero everywhere, except for the detachment area, whose cells have Q_m value equal to p_{miw}; of course, all initial values of "mobilisation flow" are zero;

Q_w is at constant value (greater than zero) only for the cells of the detachment area (where landslide debris is initially located).

Q_o and Q_{mf} are zero everywhere.

At each next step, the function σ is applied to all the cells in R, so that the configuration changes in time and the evolution of the CA is obtained.

2.3.MAIN CHARACTERISTICS OF THE TRANSITION FUNCTION s

The main mechanisms of the transition function are specified in this section.

We suppose that these mechanisms to be all-independent. This means that we only consider the values of the substates at the previous step (t-1) of the CA in order to obtain values at the successive step (t), complying with the general definition of a Cellular Automata.

$\sigma: S^6 \rightarrow S$ is the deterministic state transition. The main procedures of this function are: the debris/mud flows, run-up and mobilisation propagation calculations.

2.3.1 Debris/Mud outflows

The outflows depend on the hydrostatic pressure gradients due to differences in height (cell altitude plus debris/mud thickness) between a cell and its six neighbours. The outflows of a cell are computed in order to minimise the differences in height (altitude plus debris thickness). A relaxation rate p_r depending on p_c and p_t limits the computed outflows. [Di Gregorio & Serra 1999]. In the case of high speed of debris/mud flow, we must substitute the debris/mud run up to debris/mud thickness [Di Gregorio et al., 1999, D'Ambrosio et al.,2001]. Because of the friction between debris/mud mass and soil and the friction internal to the debris/mud mass, we assume that flows can occur between the cell and the neighbour only if the local slope angle between the cell and the neighbour is larger than the threshold p_f.

2.3.2 Run-up determination

Considering the high speed of debris/mud flow, we may not neglect the kinetic energy, as is the case of classical problem of slope stability [Di Gregorio et al., 1999]. Indeed, debris/mud flows, especially in the form of "debris/mud avalanche", may reach high speed so that they are able to override topographic highs, or to run up the opposite side of a valley after reaching its bottom. In this case, the kinetic energy of the up-running mass is transformed into potential energy, reversing the process that occurs during the slide-down, apart the fraction dissipated by non-conservative processes. In order to account for the transformation of kinetic energy in potential one, we "blow up" the debris/mud volume, reducing at the same type the density (the volume is increased, but the mass is conserved). That is realised, substituting the real debris/mud thickness with the run up, i.e. with the blown thickness. The new run up height is determined by the weighted average of all the contributions of the debris/mud inflows from the neighbours and the contribution of the central cell itself, which represents the residual debris/mud thickness in the cell, not lost because of outflows. The quantity p_{rl} is subtracted to the value obtained.

2.3.3 Mobilisation propagation

The mobilisation effect concerns the stratum fluidification, which is transformed in debris/mud, the propagation of mobilisation (mobilisation flows Q_{mf}) occurs in two cases:

a) the central cell is mobilised and the angle between the central cell and the neighbour (considering the altitude difference) is less than a fixed threshold angle p_{ma}. In this case the value of the mobilisation flows is reduced by an unit in comparison with the value of the mobilisation width Q_m of the cell. The same value Q_m is propagated for the neighbour with maximum slope if the slope angle is larger than p_{mad}, then the value p_{miw} is propagated; if the slope angle is larger than p_{mdt}, then the mobilisation width Q_m of the central cell is propagated.

b) the pressure of the inflows (it is a function of the run up value of the inflows) overcomes a fixed threshold p_{mt}, referred to the run up multiplied by debris thickness.

2.3.4 Internal transformations

The previous three mechanisms of the transition function regard the so called *local interaction* part, that is, methods that consider an interaction between the cell and the neighbouring cells. Other major processes of the transition function regard instead transformations that occur only within the cell (i.e. the neighbouring cells do not influence these transformations).

- The altitude and thickness variation by solidification occurs when the water content (Q_w) is either equal to or less than a solidification threshold (p_{so1}): in such a case, the altitude is increased by the thickness of landslide debris (Q_{th}) and then the values of thickness of landslide debris and the run up (Q_r) are set to zero.
- The drop in water content (Q_w) is due to losses occurring at the surface of the landslide; these are proportional to a first empirical parameter of water loss (p_{w1}), which depends on the type of debris and on the clock of the CA. The surface, where the water losses happen, may be approximated to the cell area (p_c * p_c); the correspondent thickness variation is approximated to a linear dependence by a second empirical parameter for the thickness loss (p_{w1}), depending also on the type of debris. The adherence (Q_{adh}) is computed according to an inverse exponential law, so that Q_{adh} has a maximum value p_{adh2}, when the water content is at the minimum value (i.e. the solidification threshold p_{so1}); Q_{adh} tends asymptotically to the minimum value p_{adh1}, according to a parameter p_{adh3}.
- The mobilisation effect concerns the fluidisation of the mantle of detrital cover, which is transformed in landslide debris. The thickness of landslide debris (Q_{th}) and the run up (Q_r) is increased by the thickness of the available detrital cover (Q_d) and then the value of the available detrital cover is set to zero. The mobilisation occurs when the propagation width substate (Q_m) is larger than 0 and the cell is affected by the landslide (i.e. Q_{th} is larger than 0).

3.PREVIOUS SCIDDICA APPLICATIONS

3.1 THE 1992 TESSINA LANDSLIDE

The Tessina landslide, which was first triggered in October 1960, is a complex movement with a source area affected by roto-translational slides in the upper sector; downhill the slide turns into a mud flow through a steep channel. The lithotypes involved in the landslide belong to the Flysch Formation (Eocene). The mud flow skimmed over the village of Funes and stretched downhill as far as the village of Lamosano (*Fig.3*). After more that thirty years, during April 1992, the Tessina landslide was reactivated, causing situations of high risk for two villages in the northern part of Italy. In that occasion, also adequate measures to safeguard the people exposed to the risk had to be considered, besides the need to monitor and check the movement's evolution.

The collapsed sector of the April 1992 event occupies a 40,000 m^2 wide area, on the left hand-side of the Tessina stream, with an approximate volume of 1 million m^3. The movement corresponds to a rotational slide with a 20 to 30 m deep failure surface, affecting also the flysch bedrock. At first it caused the formation of a 15 m high scarp and a 100 m displacement downstream with consequent disarrangement of all the unstable mass and destruction of the drainage systems set up some years earlier.

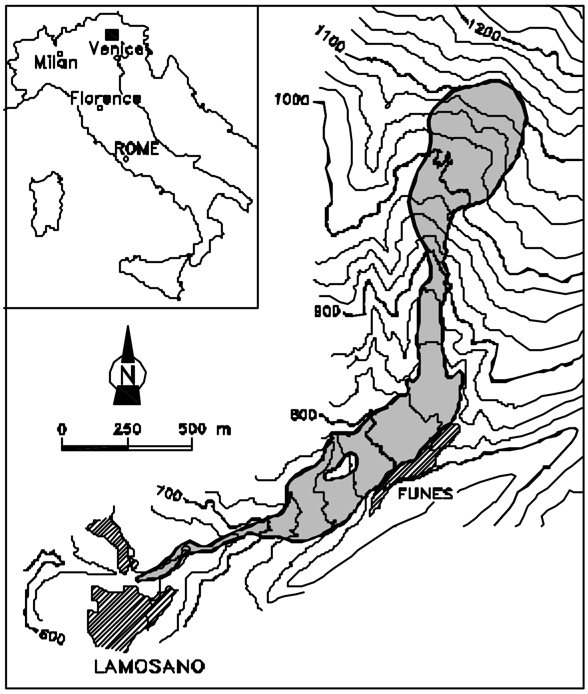

Fig. 3 *Tessina real event.*

The movements in this area continued with a certain intensity up to June, causing the mobilisation of another 30,000 m^2. The material from this area, which is intensely fractured and dismembered, was canalised along the river bed where, owing to its continuous remoulding and increase of water content it became more and more fluidified, thus giving rise to small earth flows converging into the main flow body.

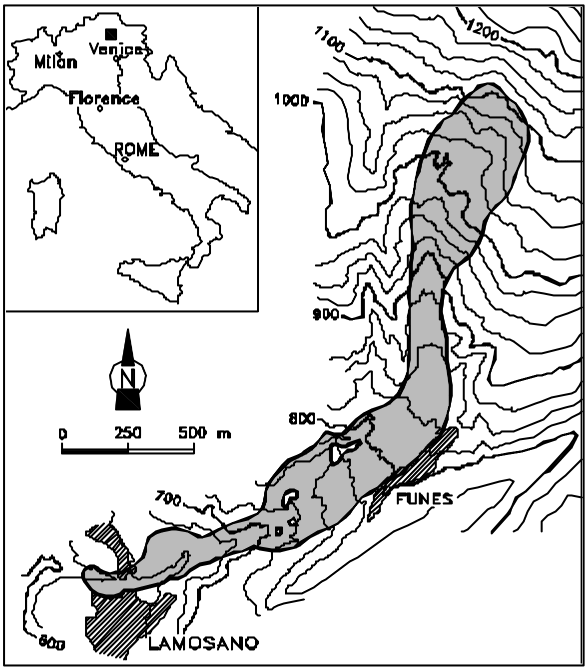

Fig. 4 *Tessina simulated. event.*

After these events the inhabitants of Funes and Lamosano were evacuated [Avolio et al., 1999a; 1999b; 2000].Some considerations and constraints, which guided us in planning the modelling and simulation of the 1992 Tessina landslide are exposed in the following.

The simulation accounts also for the very initial phase of the landslide, which can be considered with larger values of viscosity, before that a complete fluidification concludes the detachment phase. A control concerning the altitude is introduced to model this first phase: viscosity values are larger when mud is over a certain altitude, otherwise the values are lower. It accounts of the detachment process: when the mud reaches a certain altitude the mud fluidification process can be considered completed; we chose 1050 meters as such critical altitude, immediately under the detachment area. The larger viscosity is modelled using larger values of the friction angle.

Because of the high degree of saturation of the materials during all the evolutionary stages of the landslide, water content is considered constant in time and this assumption simplifies furthermore the model.

The temporal correspondence of a step of the CA was determined subsequently to the simulation tests; it can be fixed to 40 minutes.

An example among the best simulations is reported in *Fig.4*. A comparison between the real event (*Fig.3*) and the simulation (*Fig.4*) evidences a substantial agreement in the landslide development, the mud path is well individuated and all the area covered by the mud is included in this simulation. However, a small area covered by the mud in the simulation doesn't have the correspondent in the reality. So a future event of landslide in the Tessina area could be forecasted with parameters found for the simulation, since the physical characteristics of the landslide do not change significantly in time.

3.2 THE ONTAKE VOLCANO LANDSLIDE.

The Mount Ontake landslide was chosen as a study case in the past years because of the large base of information and data before, during and after the event in comparison with other cases to our knowledge (in *Fig. 5* the morphology previously the event); another reason was the possibility to compare our results directly with the results of the method developed by Sassa [1988].

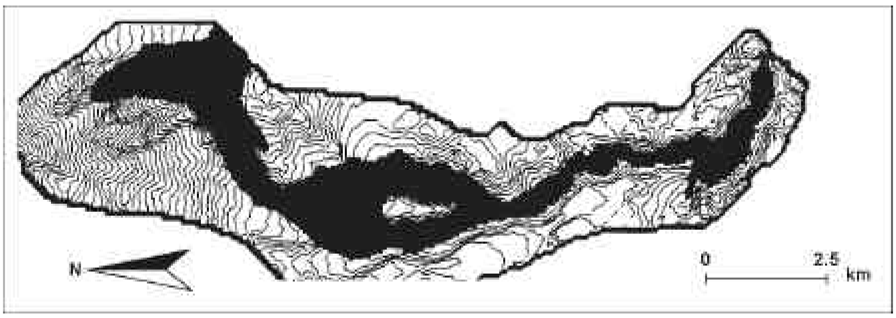

Fig. 5 *Mt Ontake real event.*

In 1984, an earthquake triggered a $3.6x10^7$ m^3 landslide on the slopes of the Mount Ontake Volcano, Japan (*Fig.5*); it moved along the Denjo river at about 20-26 m/s, with a jump of 1625 m. The landslide initiated its movement as a translational slide; the debris immediately broke down and the movement continued as a debris flow of huge size, which flowed into the Denjo River for a run out of ca. 13 km.

Due to the rugged morphology of the volcanic flanks, the movement of the mass was actually very complex; as soon after breaking down the debris hit against the opposite slope of a tributary valley of the Denjo River, and a small part of it overtopped the slope ridge. The most of the debris flowed downstream and at a distance of ca. 5.5 km from the scar, reaching a sharp bent of the river. Due to its great momentum (i.e run up), part of the flowing mass climbed up the external wall of the bent, overtopped the ridge and flowed down in the siding valley. As the two streams joined at a confluence 2 km downstream, the two branches of the landslide rejoined at this confluence, and continued flowing into the valley to the final rest.

The phenomenon was surprisingly fast and long-reaching with respect to the volume of the moving mass. This observation fact is due to the effect of sudden un-drained loading of soil by the flowing mass, and actually it is difficult to find any other physically logic explanation. Those landslide particularities justify that the debris water content is considered constant and the spooning effect is negligible.

A comparison between the real event and the simulation (*Fig. 6*) evidences a substantial agreement in the landslide development. The debris path is well individuated, but the simulated flow widths are at the beginning larger while, later, narrower since the initial cohesion is not considered (all the debris is detached simultaneously); furthermore the deposit thickness are 15% smaller [Di Gregorio et al.,1999].

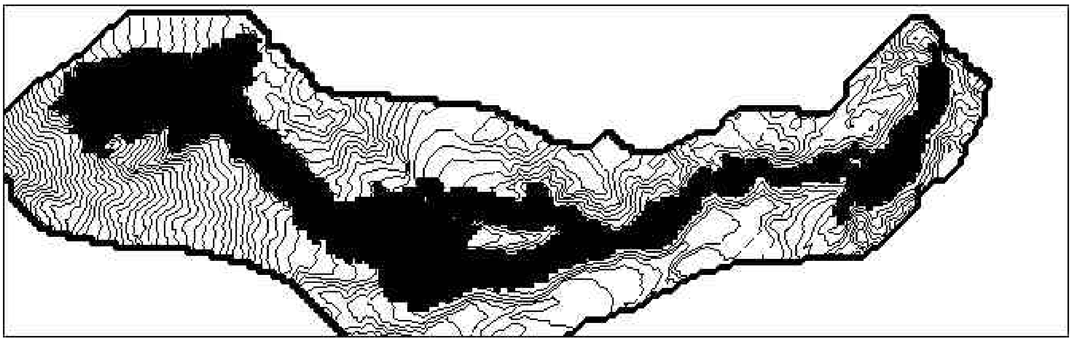

Fig. 6 *Mt Ontake simulated event.*

3.3 THE CURTI (SARNO, ITALY) LANDSLIDE.

The third and last study concerns the landslides that occurred in the Sarno area (Campania, Italy) in the May of 1998 [D'Ambrosio et al., 2001].

The Curti landslide developed at Chiappe di Sarno (the mud flow starting at bottom of *Fig. 7*), on the SW-facing slope of Mt. Pizzo d'Alvano, as a result of a prolonged rainfall period that hit Campania region on 5-6 May 1998. On the whole, ca. 150 debris slides (as for landslide classification, see Cruden and Varnes, [1996]) were triggered in the study area by the same meteoric event: many of them transformed into fast moving debris flows and hit the urbanised areas at the foot of the slopes, killing unfortunately 161 people and leaving more than 1,000 others homeless.

May 1998 debris slides mainly involved the entire volcanic detrital cover, down to the bedrock, increasing the initial volume by scraping off soil and vegetation along their paths.

In particular, the source area of the Curti mudflow was at ca. 780 m a.s.l. The moving mass rapidly transformed into a fast flowing mud-debris, and run down the slope for ca. 375 m. After encountering a convex break in slope, related to a bedrock outcrop ca. 75 m high, the flow slightly enlarged and entered the main channel, changing its propagation direction from SSW to SW. Then the phenomenon flowed down for a length of ca. 325 m, triggering some minor ("secondary") debris slides on both flanks of the channel. After that, influenced by the pre-existing morphology, it made a left turn, enlarged again and subdivided into two distinct flows. Approximately 675 m down slope, after a gentle right turn, the flows merged again and the hit the uppermost urban area of Curti.

The total length of the Curti debris slide – mud flow is greater than 150 m; the elevation of the urbanised area at the foot of the slope is ca. 115 m a.s.l.

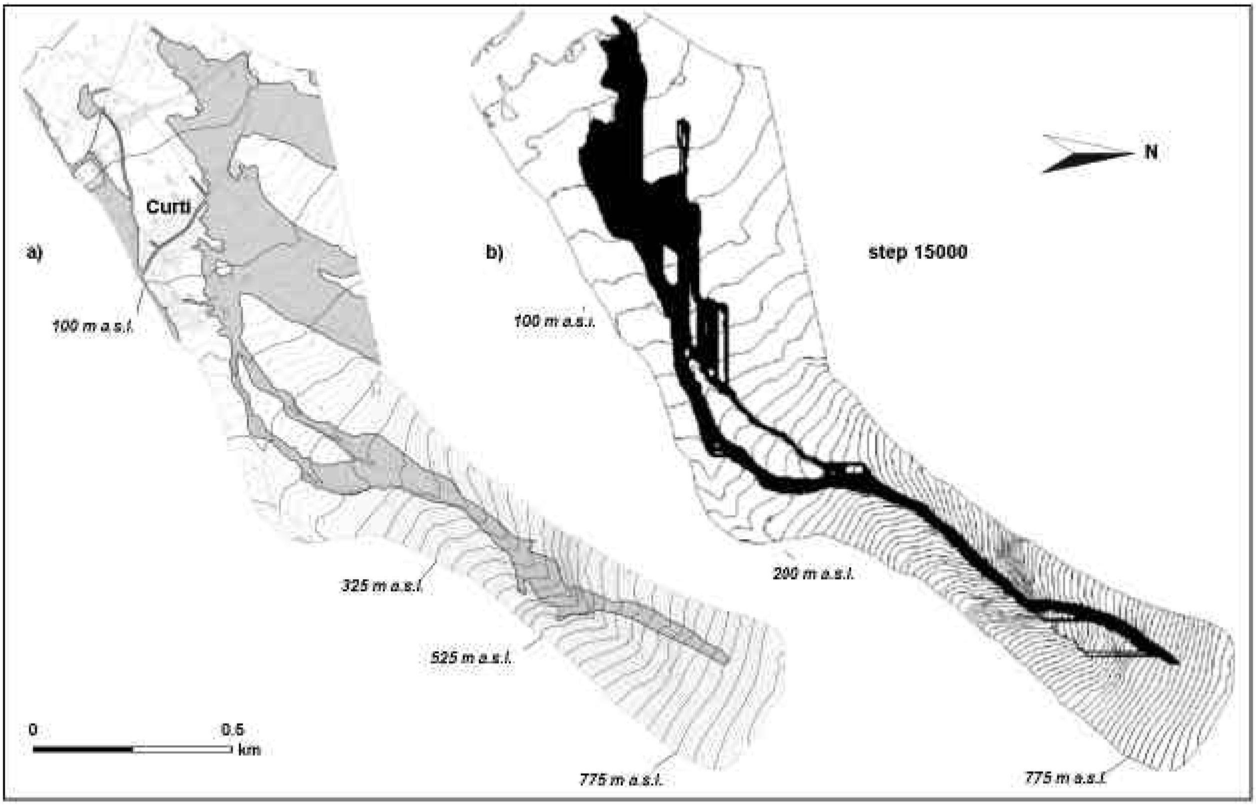

Fig. 7 ***Comparison between the simulated and real event of Curti (Sarno)***

The fact that the Sarno landslides are usually more complex than the previous ones implies that we need a larger precision on data. The edge of the cell was chosen to be dm 25; the precision of the altitude values for such a dimension of the cells is low, considering the available data. A reduced version of the transition function was applied to the simulation of the real landslide of Curti, in the Sarno area.

The detail level of morphology and detrital cover didn't permit to put the detachment area at the right place, but it was shifted in a lower area, so that the eroded mud volume in the simulation was reduced. Moreover, it must been said that we have used a square grid CA and that the present Sarno model does not take into account any water lost.

In spite of the limitations of the model implementation and data precision, the main behaviour of the landslide was captured in significant way, because the main peculiarities of the Sarno landslides were reproduced.

If we compare *Fig.7,* the simulation results acceptable especially if the full mud path is considered. Of course the suitability of the parameters may not be guaranteed for this reduced model; methods of optimisations (e.g. genetic algorithms) will be necessary for the application of the full model with precise data, but this reduced model together with the results of the applications represents the basis for further improvements.

4. CONCLUSIONS

Three distinct cases of debris flows, occurred in Italy and Japan in the last decades and characterised by different morpho-evolutive characteristics were presented.

The cellular-automata model SCIDDICA has proved to be a reliable tool in assessing the susceptibility to the considered types of landslide. Previously applied releases of the model still form the core of the latest version: this latter was, in fact, obtained by consistently adding more functions (i.e. subroutines) to the pre-existing software. In this way, the "run up" and erosive abilities of the flowing material were implemented in order to progressively simulate more complex, real phenomena.

First, preliminary simulations of a selected debris flow, occurred at Sarno in May 1998, proved to be consistent with the observed path of the actual landslide, suggesting that SCIDDICA could be usefully applied in debris-flows susceptibility analyses. However, general estimates of the model parameters can not be assessed from this first, simplified application of the model.

Future work provides to apply the model sketched in this paper to more precise data concerning the Sarno landslides: the hexagonal model permit better simulations, where a more significant comparison will be performed.

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