Supplement 5B: Review of Type II models

Table 5B.1. Review of Type II models (in chronological order) for terrestrial lava flow emplacement simulation, and the physical basis of each.

Model and/or source references		Application sites	Flow path method	Flow model type	Velocity model	Heat loss model	Yield strength model	Viscosity model	Output
SCIARA	Crisci *et al.* (1986)		CA	cool	H	Q_{rad}	$\varpi(T)$	$\varpi(T)$	1st application of CA to lava
	Barca *et al.* (1993)	Etna 1986-87							Simulation of 1986-87 flow
	Crisci *et al.* (1999)	Etna 1989							Risk assessment for three Etnean towns
	Crisci *et al.* (2003)	Etna 1991/2001							Simulation of 1991 and 2001 flows
	Crisci *et al.* (2004)	Etna 1669							Hazard assessment for Catania based on 1669
FLOWFRONT	Young and Wadge (1990)	Etna	grid	vol	-	-	τ_0	-	Lava inundation zone
	Wadge *et al.* (1994)	Lonquimay							Lava inundation zone for 1988-89 flow
		Etna							Lava flow hazard map for Etna
Ishihara *et al.* (1990)		Miyakejima 1983	CA	cool	NS	Q_{rad}	$\tau_0(T)$	$\eta(T)$	Simulation of the three flow fields
		Izu-Oshima 1986							Original cooling-limited CA
		Sakurajima 1914							
Kauahikaua *et al.* (1995)		Mauna Loa	line-C	prob	-	-	-	-	Lava flow hazard map for Mauna Loa
Miyamoto and Sasaki (1997)		Miyakejima 1983	CA	cool	NS	Q_{rad}	$\tau_0(T)$	$\eta(T)$	Simulation of 1983 flow
Miyamoto and Sasaki (1998)									Application to flood basalts
Miyamoto and Papp (2004)		Okmok 1997							Simulation of 1997 flow
Felpeto *et al.* (2001)		Lanzarote	line-S	prob	-	-	–	–	Lava flow hazard map for Lanzarote
FLOWGO	Harris and Rowland (2001)	Mauna Loa	line-C	cool	J	$Q+$	$\tau_0(T,\phi)$	$\eta(T,\phi)$	Simulation of 1984 channel conditions
		Kilauea							Simulation of 1997 channel conditions
		Etna							Simulation of 1998 channel conditions
	Rowland *et al.* (2005)	Mauna Loa							Effusion rate contour-based hazard map for ML
	Harris *et al.* (2007)	Etna 2004							Validation using LIDAR-derived channel data
Costa and Macedonio (2005)		Etna 1992	grid	cool	SWE	$Q+$	–	$\eta(T)$	Simulation of 1992 flow
DOWNFLOW	Favalli *et al.* (2005)	Etna 1992/2001/2004	line-S	prob(D)	E		–	–	Lava flow inundation assessment for each flow
	Favalli *et al.* (2006)	Nyiragongo 2002							Flow path simulations through Goma
LavaSIM	Hidaka *et al.* (2005)	Izu-Oshima 1986	CA	cool	NS	$Q+$	$\tau_0(\eta)$	$\eta(T)$	Simulation of 1986 flow
MAGFLOW	Del Negro *et al.* (2005)	Etna 2001	CA	cool	NS	Q_{rad}	$\tau_0(T)$	$\eta(T)$	Introduction to Cellular Nonlinear Networks
	Vicari *et al.* (2007)	Etna 2001							Simulation of 2001 flow
	Herault *et al.* (2008)	Etna 2006							Simulation of 2006 flow
	Del Negro (2008)	Etna 2004							Simulation of 2004 flow

Table 5B.2. Abbreviations used in Table 5B.1

Abbreviation	Description
(1) Flow Path	
line-C	Single downhill flow path is projected down a map or DEM as a line, in a method identical to that used to identify stream flow lines and water catchments
line-S	Multiple (*n*) flow paths are projected using a stochastic model that projects a downhill flow path down a DEM, adds random noise to the DEM, projects a new path and repeats *n* times to produce a field of flow paths
grid	Flow spreads across a gridded topography
CA	Cellular Automata
(2) Flow Model Type	
prob	Probabilistic: Assessment of the probability that a lava flow will inundate a given location
prob(D)	Probabilistic (DOWNFLOW): Probability of lava invasion for any given pixel down flow of a given vent is based on the ratio of the number of times a pixel is crossed by a flow path divided by the number of runs. Runs are projected to the edge of the DEM with no length limit.
cool	Cooling-limited: Lava control volume cools with time and distance, so that the core temperature declines and the flow rheology evolves until further spreading/advance is no longer possible
vol	Volume-limited: A fixed volume of lava is spread across the DEM until the volume is used up
(3) Velocity Model	
-	No velocity model applied
NS	Navier-Stokes
H	Flow across each cell is driven by hydrostatic pressure gradients set up by differences in lava thickness within surrounding cells, and the rheology of lava in the cell (Barca *et al.*, 1993)
J	Jeffreys equation for mean velocity of flow in a channel
SWE	Use of shallow water equations as introduced by de Saint-Venant (1871) and Boussinesq (1872) and used for simulations of floods and tsunami propagation. Assumes an incompressible, homogeneous fluid, a hydrostatic pressure distribution and uniform or gradually varying flow.
E	Flow length is based on empirical laws that relate flow length on Etna to vent altitude or effusion rate
(4) Heat Loss Model	
-	No heat loss model applied
Q_{rad}	Heat loss considers solely radiative heat loss (Q_{rad})
$Q+$	Heat loss model considers: radiation (Q_{rad}) and forced and/or free convection (Q_{conv}) (LavaSIM), plus conduction through the flow base (Q_{cond}) (Costa and Macedonio, 2005), as well as heat loss due to boiling and vaporization of rainwater, and surface crust entrainment (Q_{ent}) (FLOWGO)
(5) Yield Strength Model	
-	No yield strength model applied
τ_0	A constant yield strength is used to define the critical thickness of lava remains in a cell
$\tau_0(T)$	A temperature-dependent yield strength model is used. Miyamoto and Sasaki (1997) and MAGFLOW use the yield strength model of Ishihara *et al*. (1990)

$\tau_0(T, \phi)$	A temperature- and crystallinity-dependent yield strength model is used. In the case of FLOWGO this is based on a temperature-dependent treatment given by Dragoni (1989) and the crystallinity-dependent treatment given by Pinkerton and Stevenson (1992)
$\tau_0(\eta)$	Hidaka *et al*. (2005) use an empirical approach to set yield strength as a function of viscosity
(6) Viscosity Model	
-	No viscosity model applied
$\eta(T)$	A temperature-dependent viscosity model is used. MAGFLOW uses the model derived for lava of Etna's composition by Giordano and Dingwell (2003). LavaSIM also uses a model based on Eq. (5.10) based model. Otherwise the Eq. (5.9) approach is used.
$\eta(T, \phi)$	A temperature- and crystallinity-dependent viscosity model is used. In the case of FLOWGO this is based on a temperature-dependent treatment given by Dragoni (1989) and the crystallinity-dependent treatment given by Pinkerton and Stevenson (1992).
$\varpi(T)$	Temperature-dependent adherence parameter that defines the thickness of lava that cannot flow out of a cell due to rheological resistance, whereby $\varpi = a\, e^{-bT}$. For Etnean flows, a and b have values of 2.17×10^5 m and 0.0092 K^{-1}, respectively (Barca *et al.*, 1993).

References in support of Tables 5B.1 and 5B.2

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