Costa, John E. 1984. Physical geomorphology of debris flows: in Costa,J. E., and Fleisher, P. J., eds., Developments and Applications of Geomorphology, Berlin, Springer-Verlag, p. 268-317.

I. Introduction
  A. Debris Flows and Damage
    1. dollars and death yearly
    2. Japan, Peru, Indonesia, Africa, China Russia.... death and destruction everywhere
      a. it's a crying shame
      b. send more tax dollars immediately!!!

  B. Debris Flows
    1. gravity-induced mass movement
    2. transitional between flooding and landsliding with different mechanical characteristics than each
    3. rapid flow of granular solids, water and air (solids 65-80% observed)
    4. viscosity variable according to mixture
    5. variations
      a. mudflows: sand, silt and clay
      b. lahars: volcanic mudflows
      c. tillflows
      d. debris avalanches

II. Origins and Types of Debris Flows

  A. genesis
    1. poorly sorted rock and soil debris mobilized on hillslopes and channels
      a. gravity
      b. moisture increase (rain, snowmelt, glacial outburst)
      c. sparse vegetation
      d. unconsolidated materials

    2. Most prone areas: small, steep drainage basins... why?
      a. rain drop > proportion of water to small basins
      b. high elevations, steep slopes (> 30 degrees)
      c. moisture >, > pore pressure

    3. Threshold relations
      a. $I=14.82\ D^{-0.39}$ where I = rainfall intensity (mm/hr), D = duration in hours

  B. Lahars
    1. volcanic debris flows, may be hot or cold in origin
      a. rainfall
      b. rapid eruption melt of snow caps, glaciers
      c. rapid drainage of crater lakes
      d. pyroclastic flows that bulk up in water from mixing and melting of eroded snow
      e. seismic-induced instability
      f. failure of landslide-dammed lakes

C. Tillflows
  1. glacial debris flows at ice front during melting
    a. slumping of seds. over ice
    b. backwasting of sed. laden slopes of stagnant ice
    c. ablation of debris-laden ice

III. Failure Mechanisms

A. conditions
  1. steep slopes > 15-20 degrees
  2. large influx of water
    a. saturation of pore space
    b. pore pressure increases
      (1) rate of deep percolation < rate of surface infiltration
      (2) decreases shear strenght, failure
      (3) spontaneous liquefaction and flow
    c. shear strength decreases
  3. originate in head-of-hollows commonly
    a. initial failure: slide, slump or topple
    b. transformation downslope to debris flow
      (1) via dilatency- increase in bulk volume of soil mass, > pore volume, > failure
      (2) incorporation of additional water
      (3) liquefaction

    c. change in resisting force from sliding friction to internal viscosity of flow
      (1) allows rapid velocity > down slope

IV. Characteristics of Flowing Debris

A. General
  1. relatively few direct observations, but some exist and are summarized in a table

B. Character

  1. commonly use preexisting drainage ways, although can use open slopes
    a. levees form to contain flow
    b. "surging wet concrete moving down valley"
      (1) surges: temporary damming and breaching of channels by debris
      (2) surges commonly carry largest boulders
      (3) surges followed by more fluid, watery slurries

  2. Vel. observed 0.5-20 m/sec
  3. Texture of flow
    a. 10-20% silt and clay
  4. Non-newtonian rheology: viscosity up to 8000 poises
  5. water content: 10-30%
  6. capacity to carry large boulders many miles

7. High erosive capacity on channel sides
    a. up to 6 times the shear stress on channel beds compared to flood flow
        (1) bedrock scour observed: 4 m in less than 24 hours

8. Mobility of debris flows over gentle slopes
    a. function of clay content
        (1) 1-2% clay, < permeability, > pore pressure in fluid, > mobility

9. other
    a. ground shaking, loud rumbles/sound

V. Physics of Debris Flows

A. Impact Force
1. very high impact force
    a. tree uprooting
    b. houses removed etc.

B. Shear Strength
1. > sediment concentration, > viscosity, > shear strength to flow

    a. shear strength K - internal strength of mass that must be overcome by critical shear stress before motion takes place
        (1) source: fine matrix, cohesive
        (2) coarse clasts = friction internally (interlocking)

C. Viscosity

1. Debris flows: are they Newtonian or Bingham fluids??

D. Coulomb-viscous Model

1. plastico-viscous bingham fluid models

E. Dilatant Model

F. Boulder Transport and Suspension of Solids
1. General
    a. boulders commonly transported
    b. "float" or weakly tumble in flow
    c. commonly deposit as diamicts
    d. what keeps these big boys floating at top of flow???

2. mechanisms of boulder support and transport

    a. Cohesion: clay -water slurries as support medium
        (1) > density, increased internal strength to support
    b. Buoyancy: density differences
    c. Dispersive Pressure
        (1) Bagnold concept from 50's
            (a) during shear flow, largest clasts drift towards free surface

(b) commonly find boulders at top and front of flow

d. Turbulence

e. Structural Support: grain to grain contact and support

VI. Deposition of Debris Flows

A. conditions of deposition

1. low gradient areas of decreased confinement
   a. e.g. fans at trib. mouth, spreading, thinning, deposition
   b. < fluids, > internal friction... deposition

2. debris flow generation: complex between precip. and sed. supply

B. Alluvial fans and debris flows; d.f. common on fans in west

1. pretty good fan discussion on facies and deposition

VII. Differentiation of Water Floods and Debris Flows

A. Introduction

1. continuum: water floods to debris flows
2. floods
   a. mud floods vs. clear water floods
      (1) clear water floods: solids separate from liquids during deposition
      (2) debris flow: en masse deposition with little phase separation

3. Waterfloods
   a. turbulent water flows with small amount of seds.
   b. deposits: stratified, sorted to poorly sorted

4. Mudfloods = hyperconcentrated flows
   a. stream flows enriched in sediment (40-70% seds)
      (1) e.g. Rio Puerco, NM

summary comparison

Flow	sed. load	bulk density	fluid type	deposits
water flood	1-40%	1-1.3 g/cu. cm	Newtonian	stratified
hyperconc. flow	40-70%	1.3-1.8 g/cu. cm	Newtonian?	poorly sorted weak strat.
debris flow	70-90%	1.8-2.6 g/cu. cm	Visco-plastic	diamict, levee-lobe

** all three flow types may exist at any given time during a given event

B. Field Evidence

1. field data, land forms, sedimentology
    a. presence or absence of bouldery levees and fans
    b. sed. of deposits
    c. extent of veg. damaage
    d. extent of ground litter disruption below high water marks
    e. gaging station records

2. Levees and terminal lobes

    a. common in debris flows

3. boulder berms

    a. open framework gravels and boulders adjacent to drainage ways
        (1) large boulders at top of berms
        (2) no matrix
        (3) localized of short occurrence along channels

    b. origin? a mystery:

        (1) slip faces of boulder dunes/deltas?
        (2) macroturbulence features?
        (3) kolk vortex action?

C. Sedimentologic Evidence

1. diamict common in debris flows
    a. matrix supported boulders
        (1) matrix washing may result in clast supported
    b. woody debris, organics
        (1) commonly floats
    c. bedding and sorting poor

2. water-laid seds.
    a. sharp bedding contacts
    b. stratification
    c. cut and fill
    d. imbrication of clasts
    e. percussion marks from turbulence on clasts
    f. open-framework gravels

3. examples of textural analysis for use in i.d. process
    a. trask sorting factor
    b. grain plots, etc.

D. Vegetation Damage

1. water floods turbulent
    a. scar and destroy veg. in path of flood

2. debris flows
    a. complete removal of all veg. and trees
    b. sheared trees suggesting lift off of channel bottom

E. Gaging Station Records

1. examples of gage records, case studies

F. Estimating the Discharge of Sediment Bearing Flows

1. paleohydraulic methods will be screwed up if applying water flood techniques to debris flow
    a. will greatly over estimate flood discharge
    b. diff. rheology than water, e.g. Mannings eq. would not work

G. Empirical Formulas

1. gives e.g. of formulas that have been modified for use with debris flows to determine vel., Q, etc.

H. Bulking Factors

I. Superelevation of Flows around channel bends and Runup

1. Tendency for fluid flows to reach higher elevations around outside of channel bends than on inside
    a. superelevation common in debris flows
    b. centrifugal force and radial accleration around bend
        (1) may be used to determine flow velocity, e.g. given using Newtonian physics

J. Photographic Techniques

1. on site radar guns, videos etc. used to reconstruct flows and velocities

VIII. Mitigation of Debri-Flow Hazards

A. Avoidance of Hazardous Areas
B. Control of Grading, clearing and drainage
C. protective structures
D. warning and evacuation

IX. Further Research

A. Cause, moisture conditions, ppt
B. field identification
C. mechanisms
D. characteristics
E. flow parameters and paleohydraulics of debris flows?
F. Occurrence and risk analysis, recurrence estimates.