NASA-CR-199155

FINAL
IN-91-CR
OCIT.
63356
P-27

Final Report
Contract NASW-4671

Boeing
Defense &
Space Group

Asteroid entry in Venusian atmosphere: pressure and density fields effect on crater formation

Robert Schmidt
Orgn 9-5574 M/S 8H-05
Seattle WA 98124-3999
(206) 773-1113
March 14, 1995

(NASA-CR-199155) ASTEROID ENTRY IN VENUSIAN ATMOSPHERE: PRESSURE AND DENSITY FIELDS EFFECT ON CRATER FORMATION Final Report (Boeing Defense and Space Group) 27 p   N96-12992

Unclas

G3/91 0063356

Objectives

- Look at times scales of overpressure compared to cratering.
- What are the transient pressure and density due to atmospheric entry?
- Does shock wave evacuate ambient gas?
- Does transient atmospheric disturbance "settle down" during cratering?
- Can the pressure/density field be approximated as quasi-static?
- How does disturbance scale with impactor size?
- What is the role of atmospheric thickness?

General approach

- Perform inexpensive exploratory calculations (Phase 1).

- Experiments to validate code and observe crater growth.

- Follow up with more realistic coupling calculation (Phase 2).

MAZe Code Description

- **CFD code developed and continually evolving under various government contracts (DNA, NASA/JPL, NSF/USGS)**
  - Formation of dust, water, ice clouds from nuclear and high explosives
  - Fireball expansion, airblast propagation, boundary layer analysis

- **Relevant capabilities**
  - Adaptive zoning automatically refines the grid where "needed"
  - TVD (Total Variation Diminishing) finite differencing
    Employs linearized Riemann solver, second-order accurate, flux limiting
  - Multiphase physics treats the mutual interactions between a gas mixture and the solid/liquid particles contained in that gas
  - ALE (Arbitrary Lagrangian Eulerian) grid techniques track physical interface between different type materials

MODELING ASSUMPTIONS
Venus Atmosphere

- **Temperature profile from Seiff (1983)**
  - — 90 bar pressure, 733 K temperature at surface ,
  - — Treated as 100% CO2

- **Non-ideal gas EOS (equation-of-state)**
  - — Variable γ, of form $P = \rho(\gamma - 1)e$
  - — Requires γ- vs-T, γ-vs-e
    - ° 111 K < T < 3000 K fit from gas tables (Keenan and Kaye, 1945)
    - ° Assume $\gamma = 1.15$ for T > 3000 K

Approach (Phase 1)

- **Asteroid penetration through Venusian atmosphere**
  - Calculate bow shock environment ahead and behind body
    - pressures, temperatures
    - include deceleration of asteroid

- **Treat asteroid as spherical, rigid body**
  - 1 km diameter, 2 gm/cc density >> Mass ~ 10^{15} gm

- **Transparent boundary**
  - Asteroid passes through planet surface without distortion

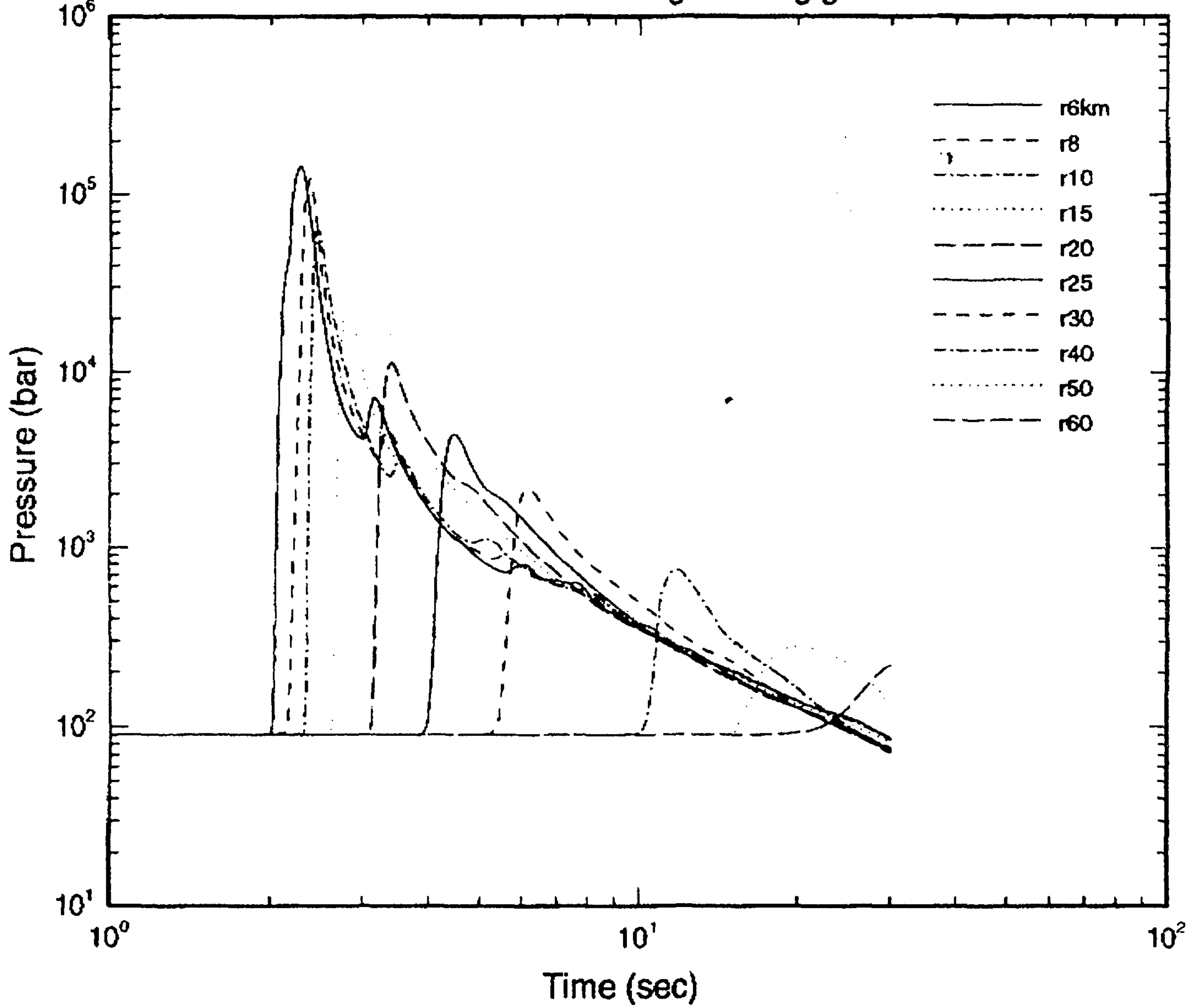
- **Minimum zone size**
  - 0.125 km for 1 -km diameter impactor

Look at 2 impactor sizes

- 1 km diamter and 10 km diameter.
- Initial velocity equal to 20 km/s for each.
- Start leading edge at 40 km altitude.
- 10-km body impacts at 19.5 km/s; transit time = 2.01 sec.
- 1-km body impacts at 15.7 km/s; transit time = 2.16 sec.
- Peak pressure is 125 kbar and 75 kbar respectively.
- Disturbance is due to the bow wave only.

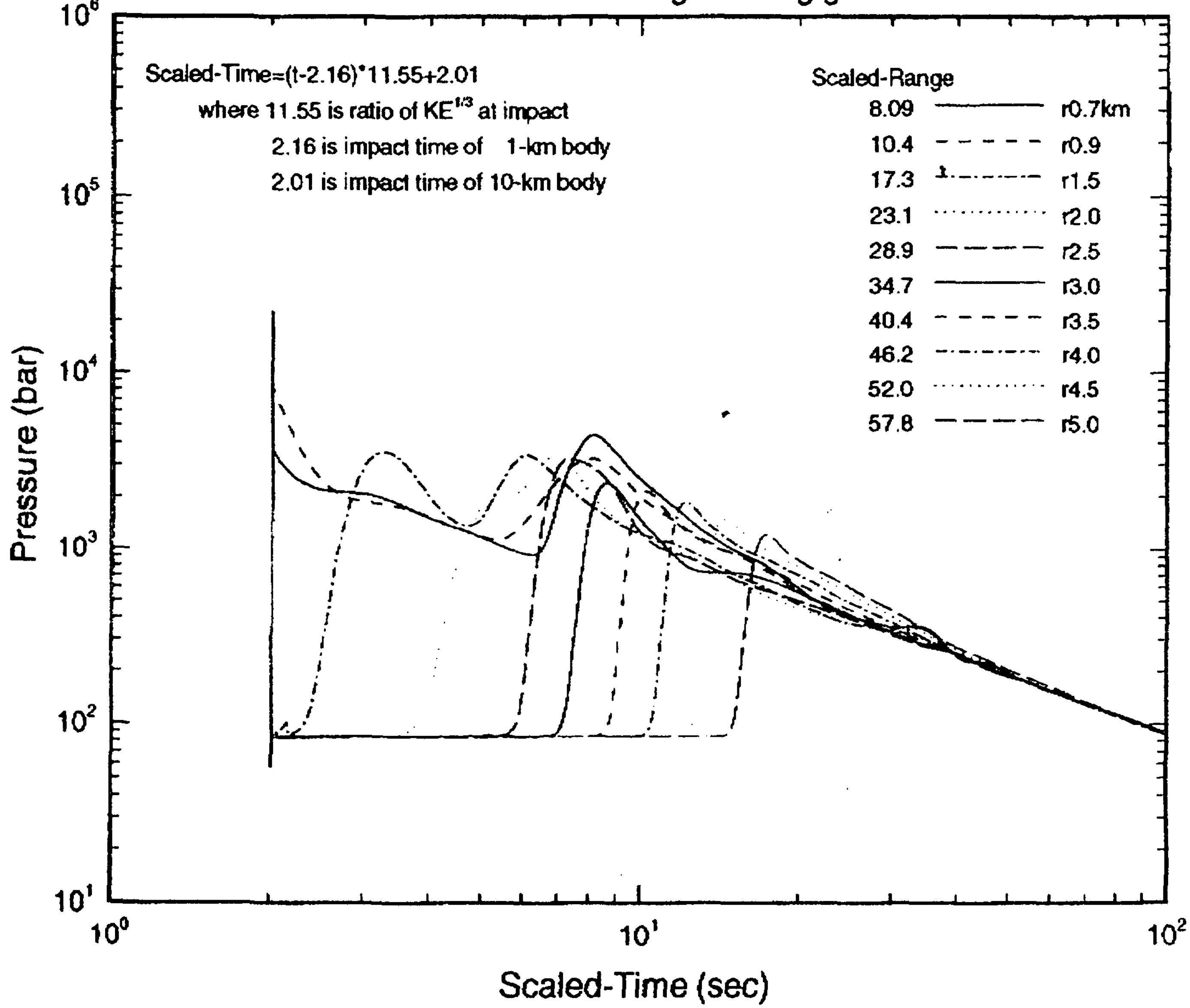
Case VEN01 10 km diameter at 20 km/s on Venus r07 venpl1

Pressure time histories at various ranges along ground surface



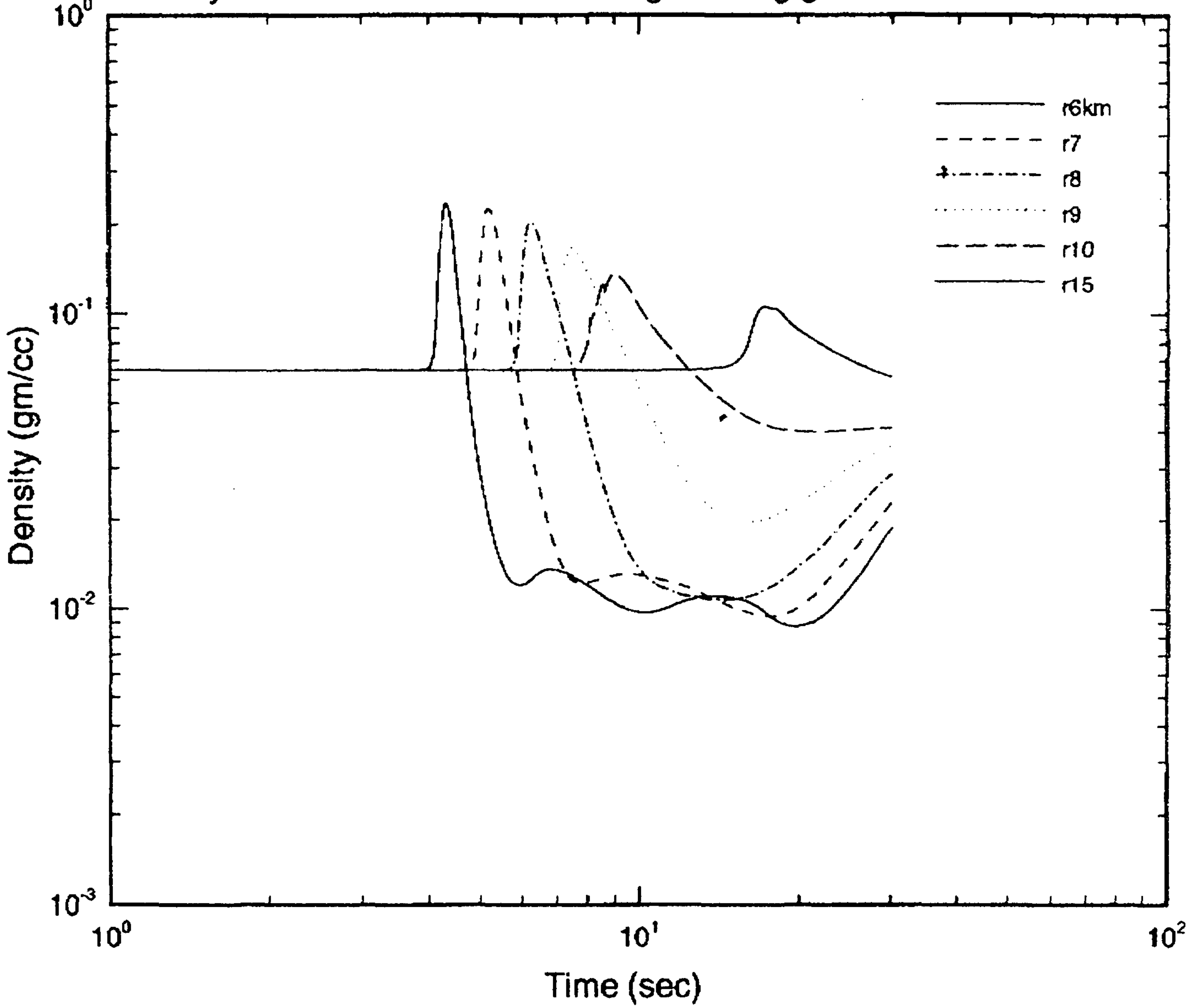
Case VEN02 1 km diameter at 20 km/s on Venus r05 venpl1

Pressure time histories at various ranges along ground surface

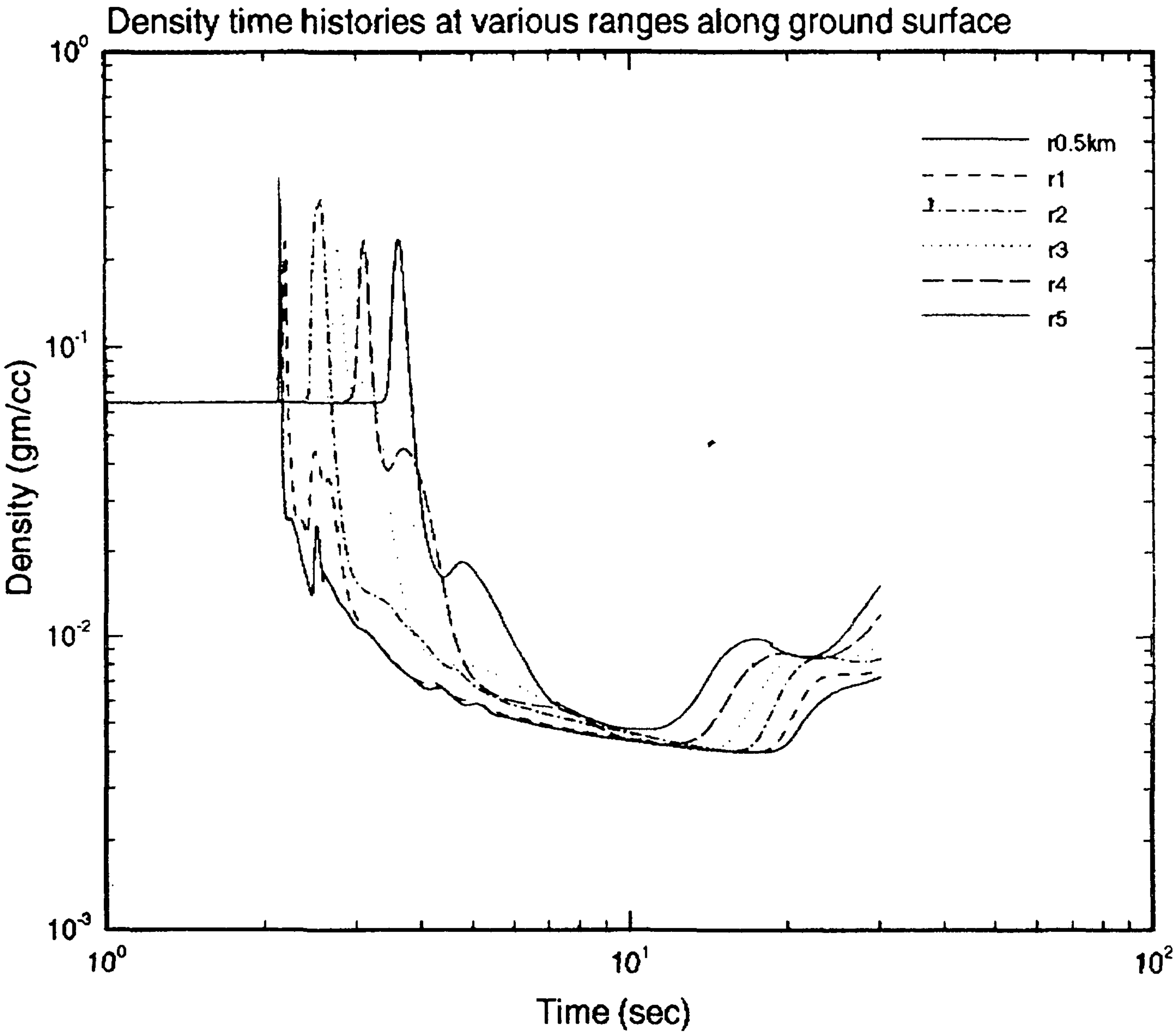


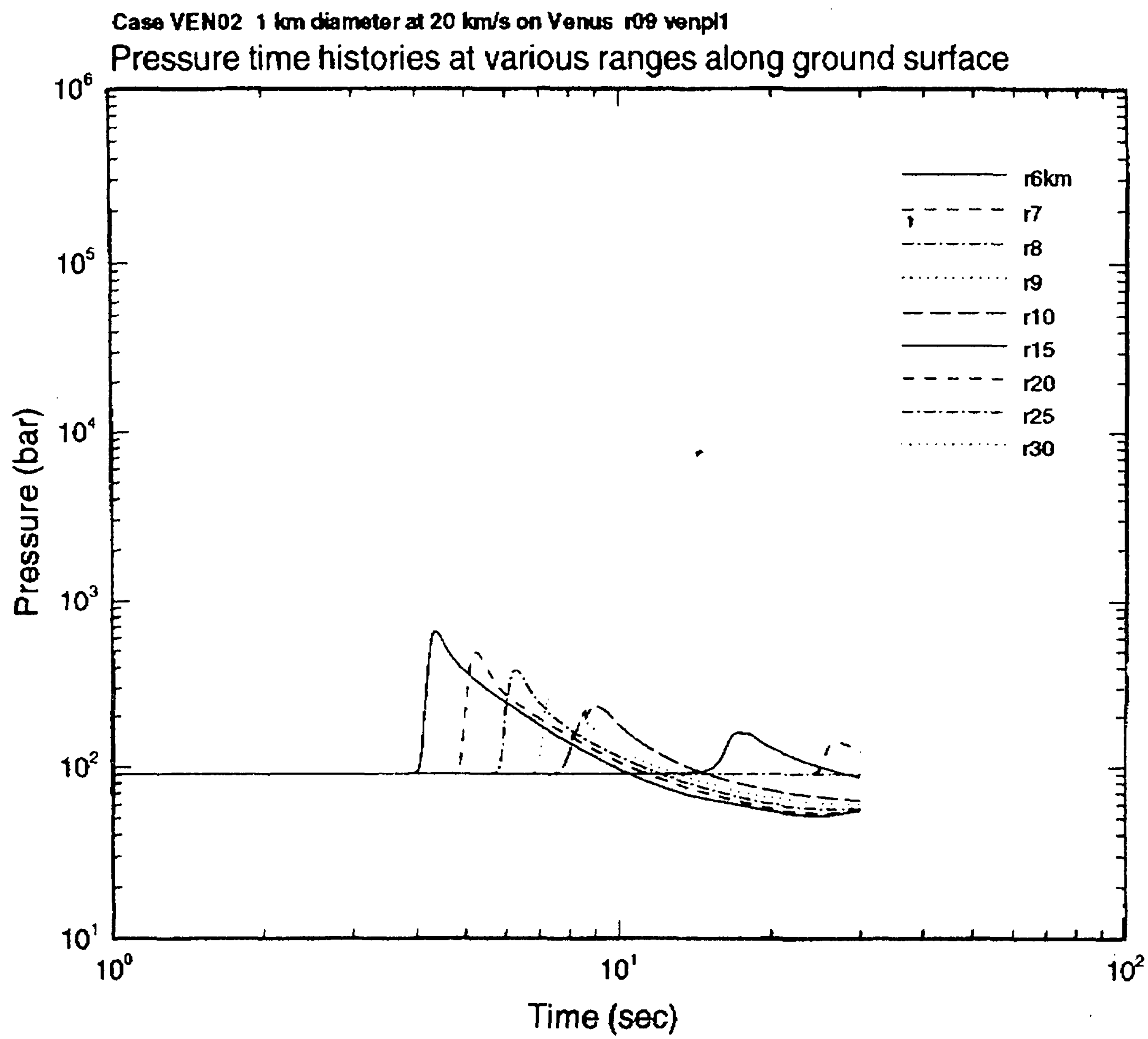
Case VEN02 1 km diameter at 20 km/s on Venus r09 venpl1

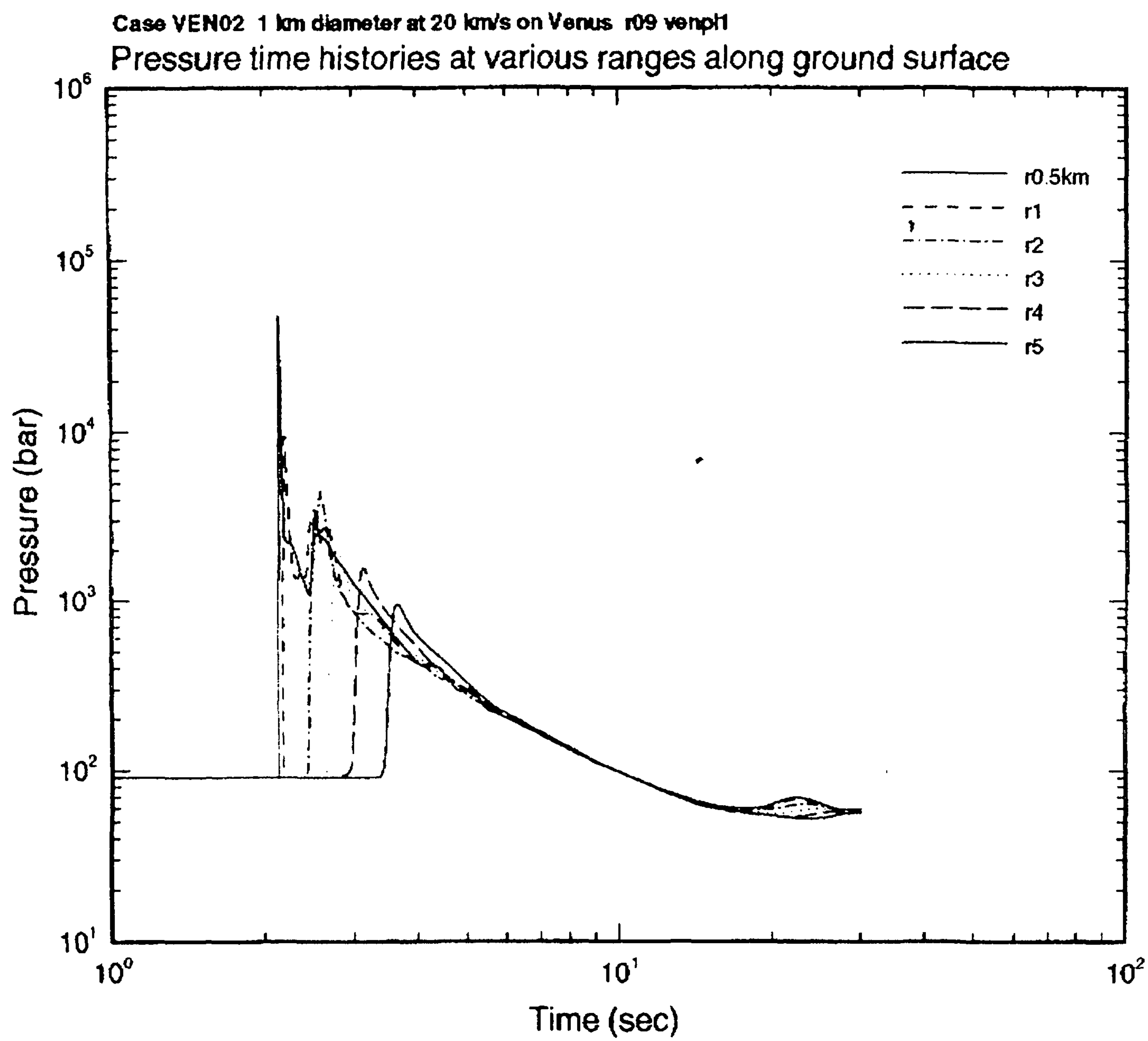
Density time histories at various ranges along ground surface



Case VEN02 1 km diameter at 20 km/s on Venus r09 venpl1

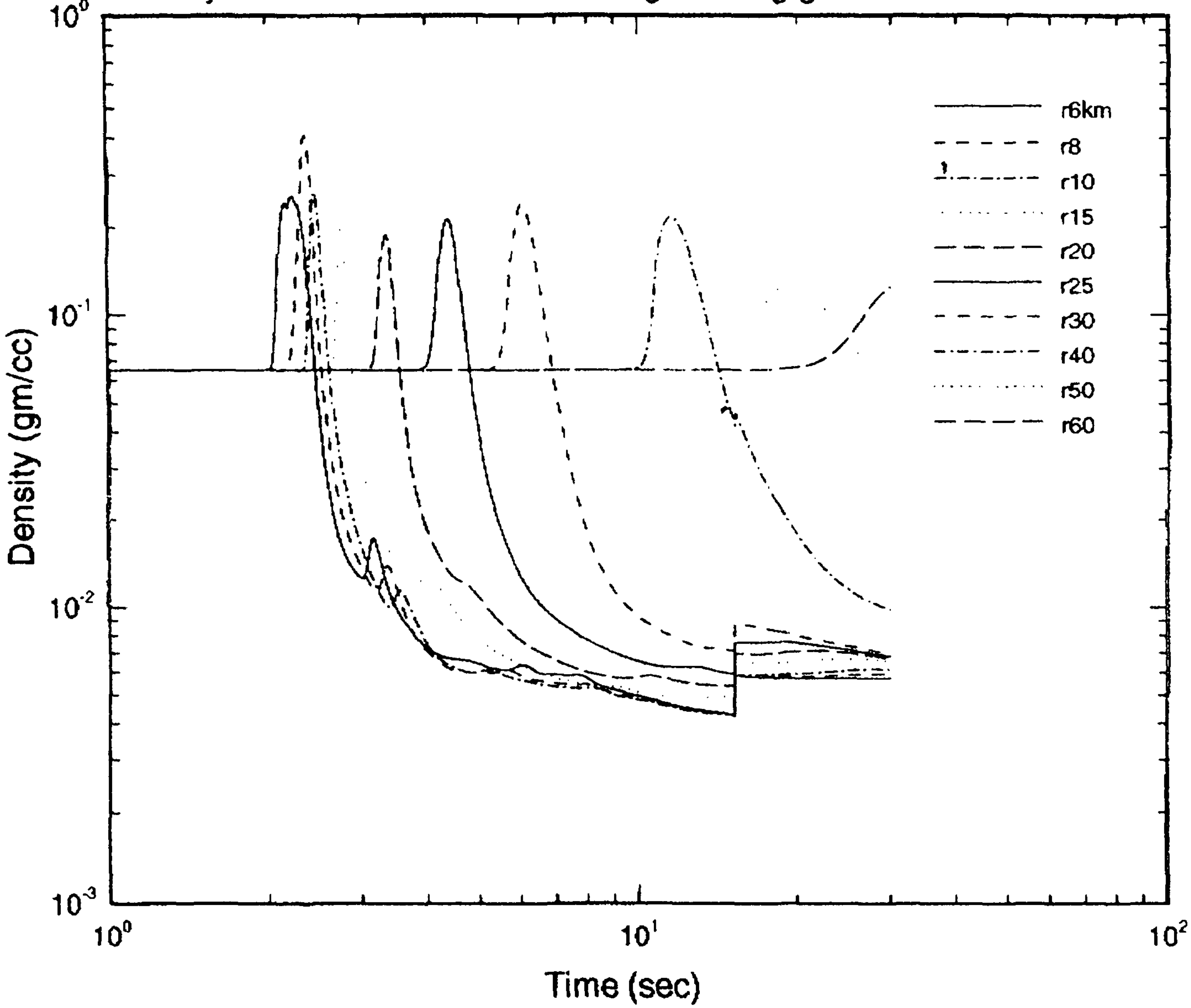



Case VEN02 1 km diameter at 20 km/s on Venus r09 venpl1
Pressure time histories at various ranges along ground surface
Pressure (bar)
Time (sec)
10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^1
10^2
r6km
r7
r8
r9
r10
r15
r20
r25
r30


Case VEN02 1 km diameter at 20 km/s on Venus r09 venpl1
Pressure time histories at various ranges along ground surface
Pressure (bar)
Time (sec)
r0.5km
r1
r2
r3
r4
r5

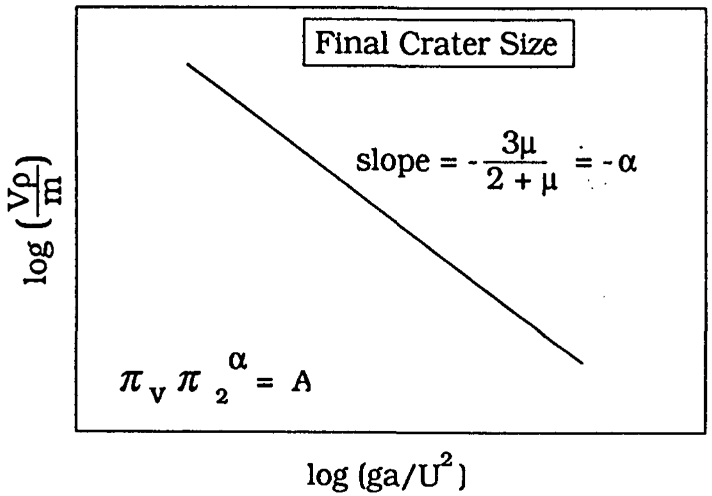
Case VEN01 10 km diameter at 20 km/s on Venus r07 venph1

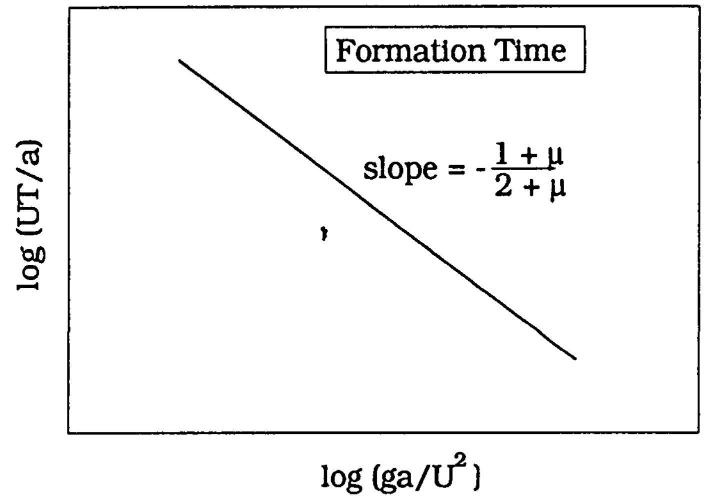
Density time histories at various ranges along ground surface

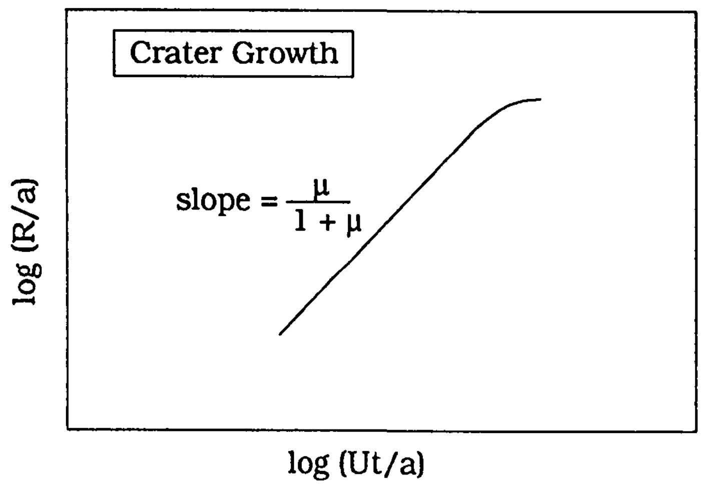


Vacuum or small π_p scaling laws

Coupling Parameter: $C \propto aU^{\mu}$







Dependence of exponents on material type

	α	μ	Crater Size	Form Time	Rate of Growth
Mom. Limit	3/7	1/3	0.429	0.571	0.250
Dry Soil	0.507	0.407	0.507	0.585	0.289
Wet Soil	0.600	0.500	0.600	0.600	0.333
Water	0.650	0.553	0.650	0.608	0.356
Energy Limit	3/4	2/3	0.750	0.625	0.400

A schematic illustration of how some of the power-law scaling relationships, which result from a point-source coupling parameter, are interrelated by the scaling exponent, μ.

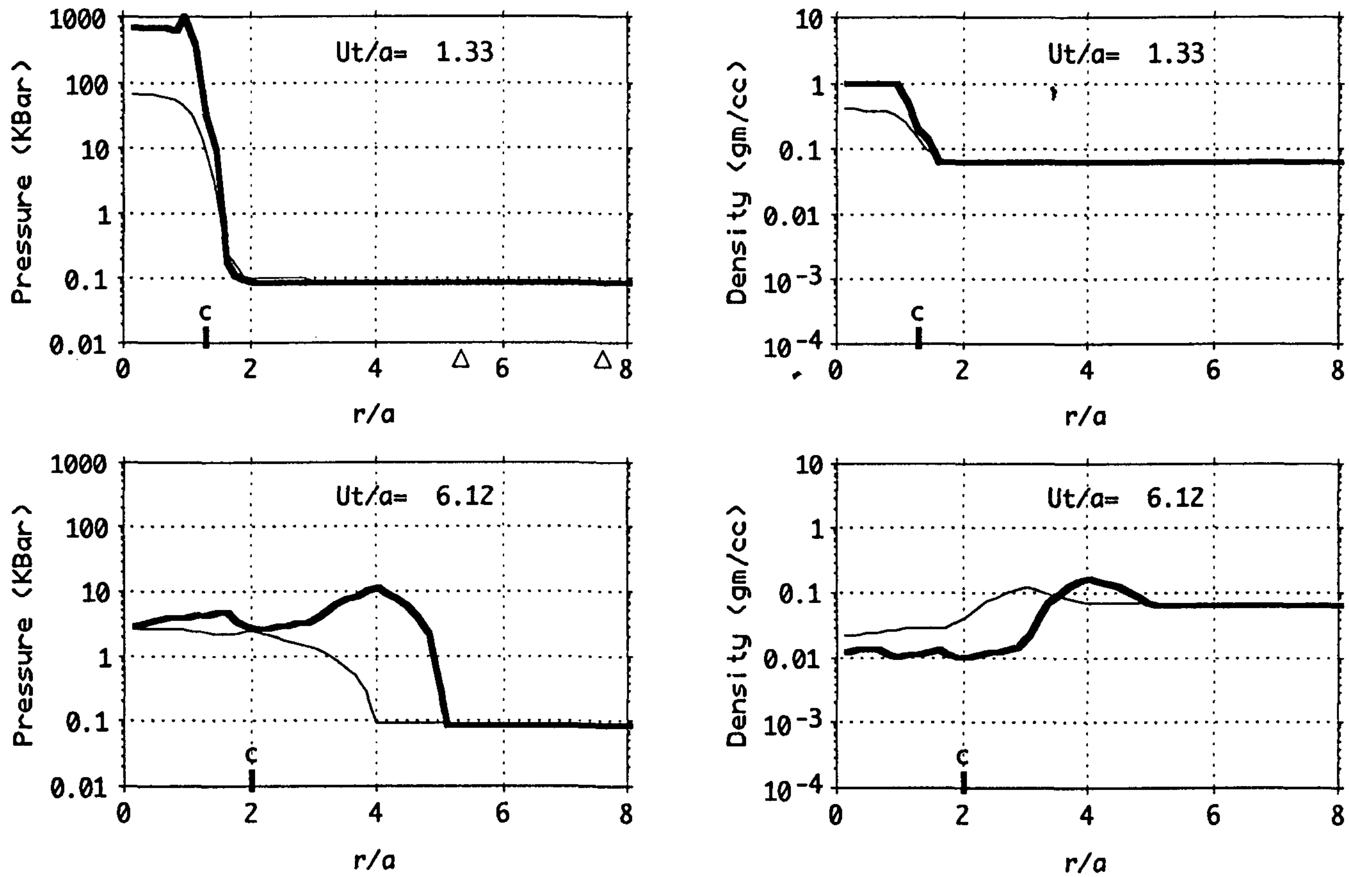
PRECEDING PAGE BLANK NOT FILMED

Vacuum crater size, time, and growth

• Impactor Size	1-km dia	10-km dia
• π_2	3.57 E-5	3.57 E-4
• Final crater size	3.9 km	26.5 km
• R/a	7.8	5.3
• Time of formation	18.2 sec	47.5 sec
• π_T = UT/a	312	190
• Growth (km, sec)	$R = 1.70t^{0.287}$	$R = 8.76t^{0.287}$

Test for cube-root scaling

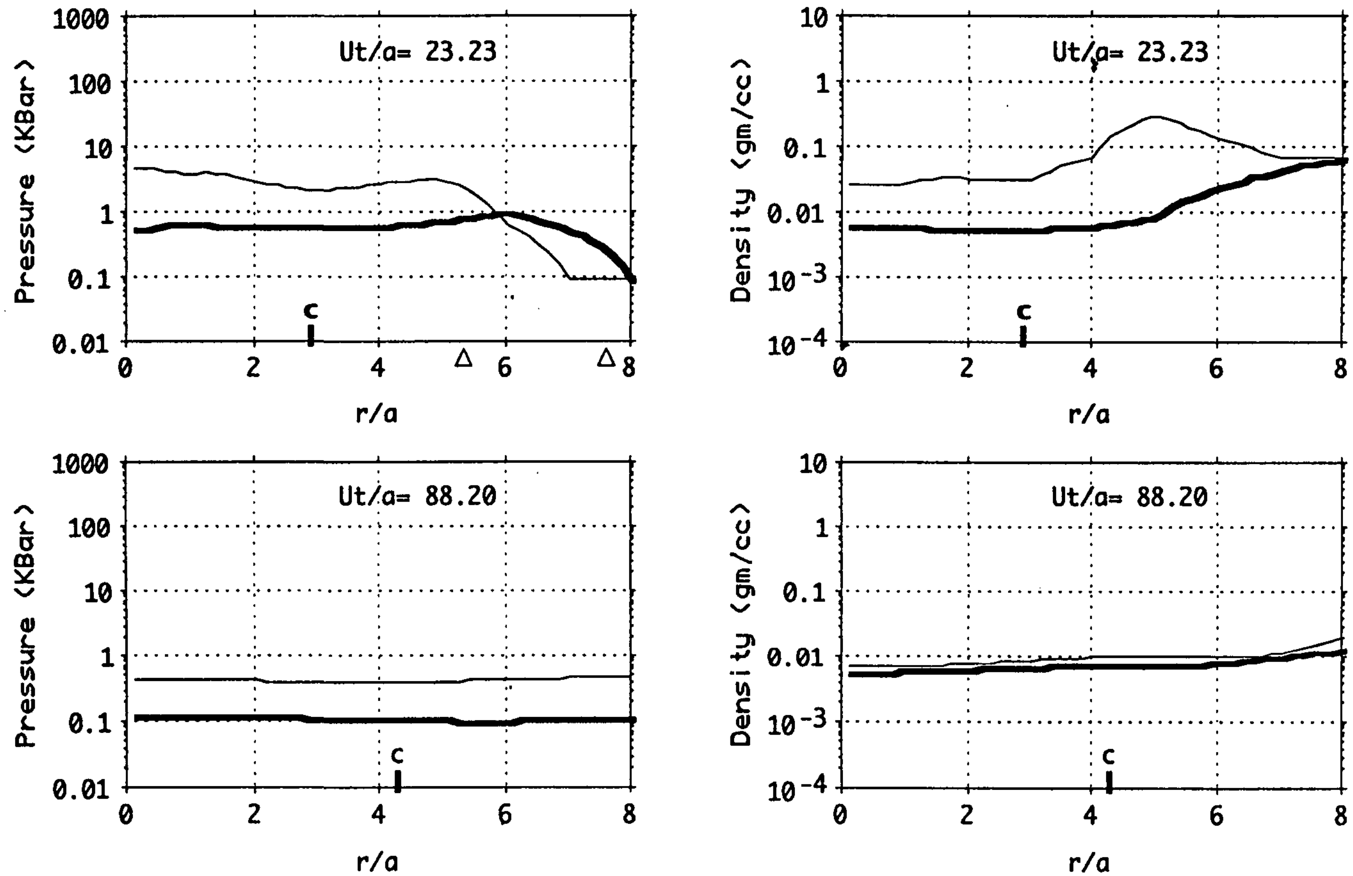
small 0.5% volume and large 1.5% volume



small 1.7% volume and large 5.4% volume

Test for cube-root scaling (cont.)
Need better interpolation and longer times

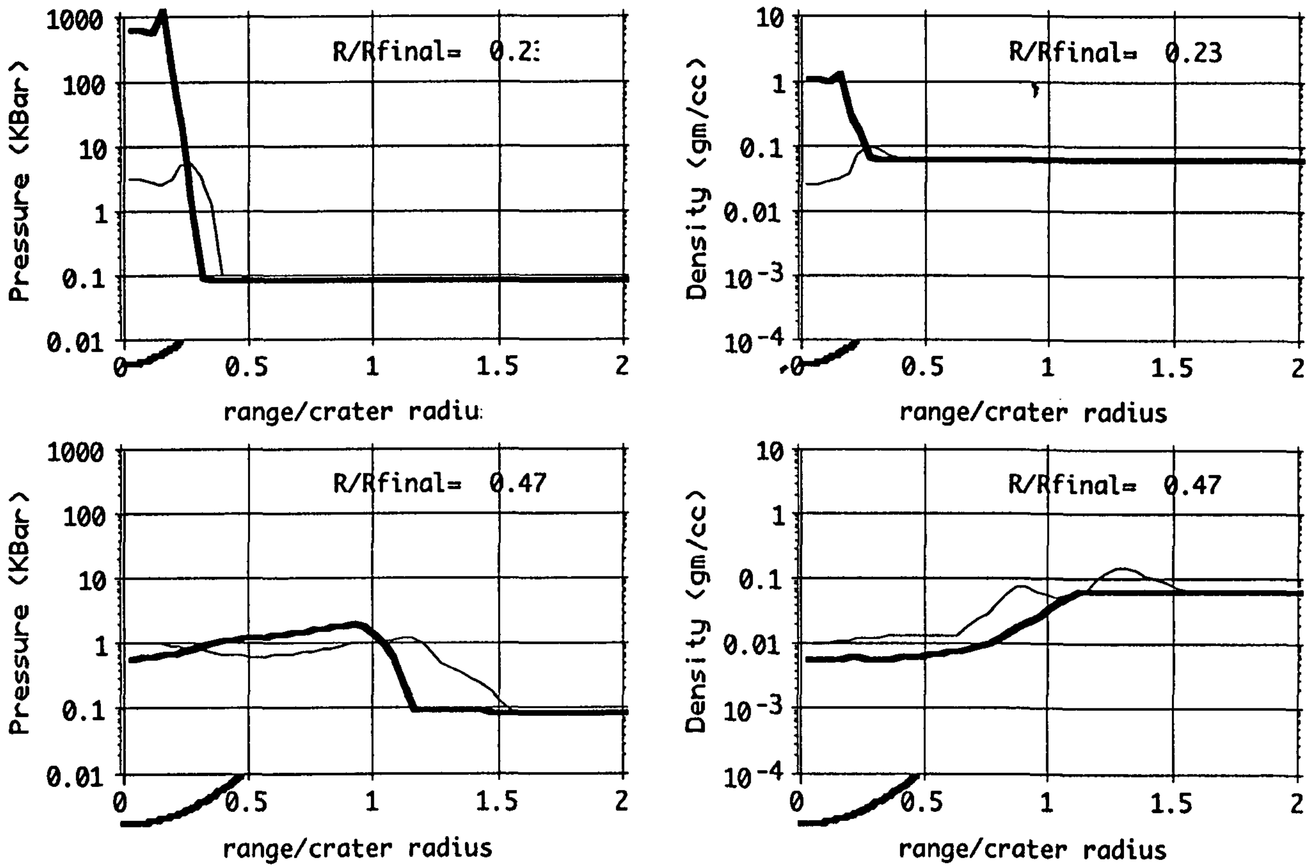
small 5% volume and large 16% volume



small 17% volume and large 53% volume

Gravity-scaled crater growth

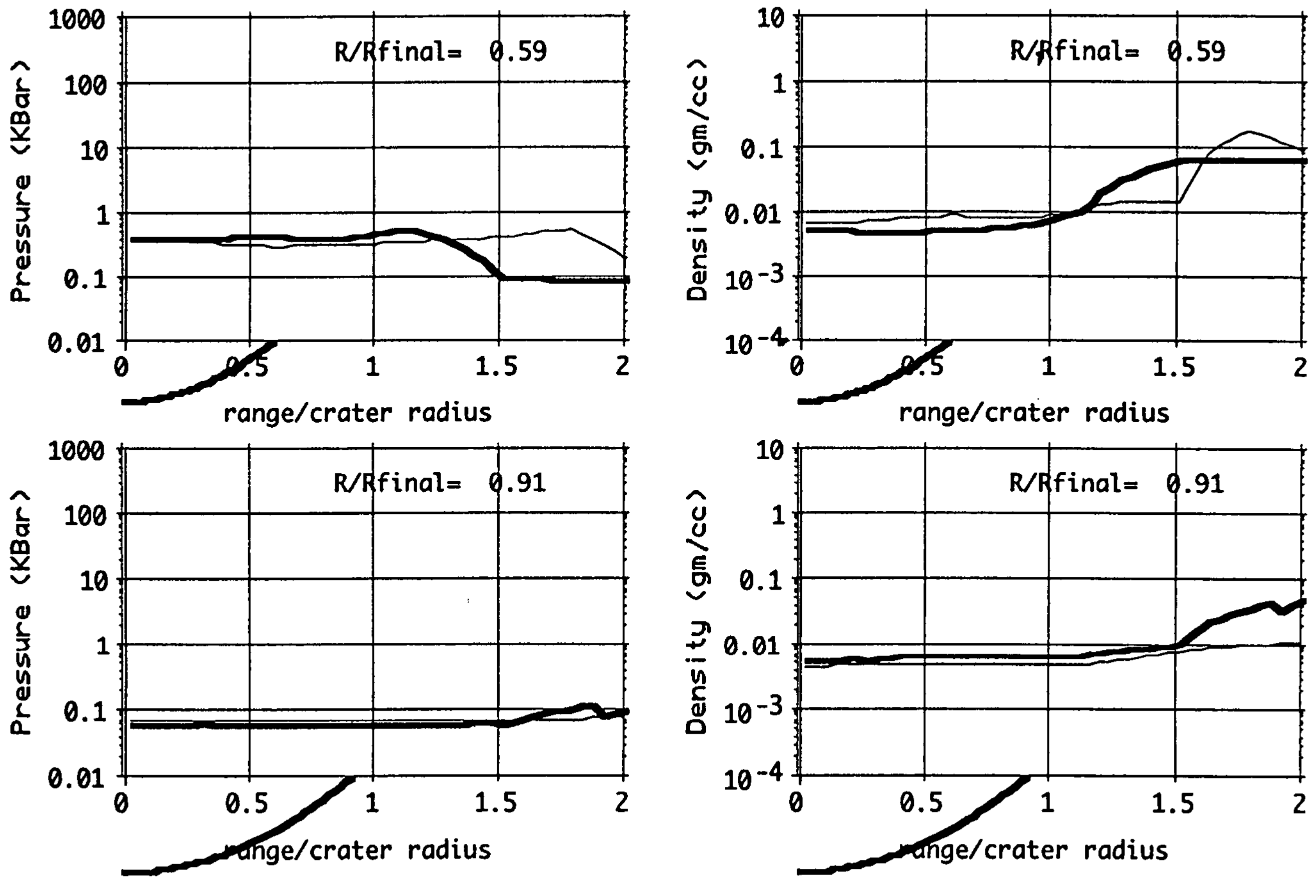
1.2% volume



10% volume

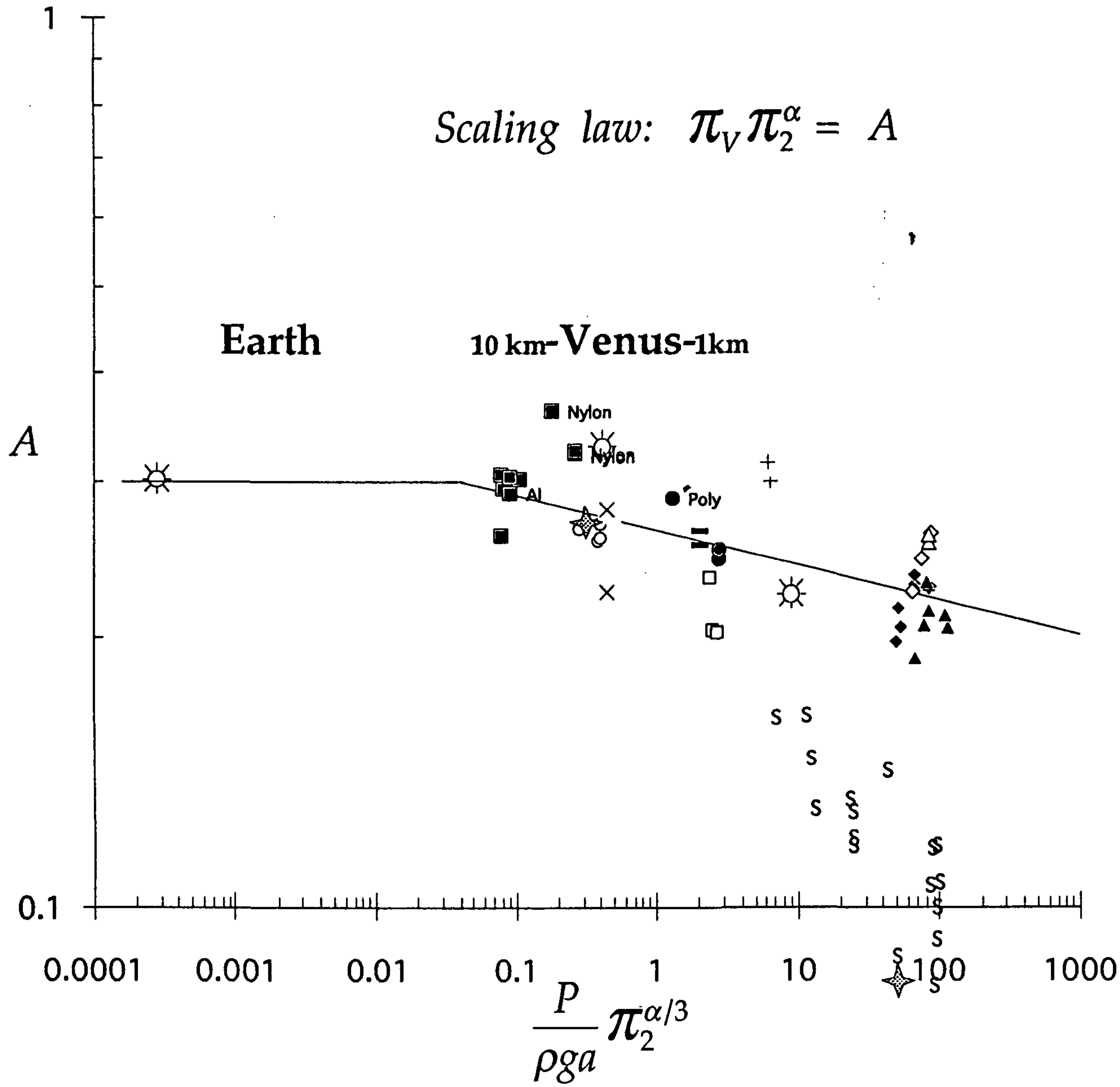
Gravity-scaled crater growth (cont.)

20% volume



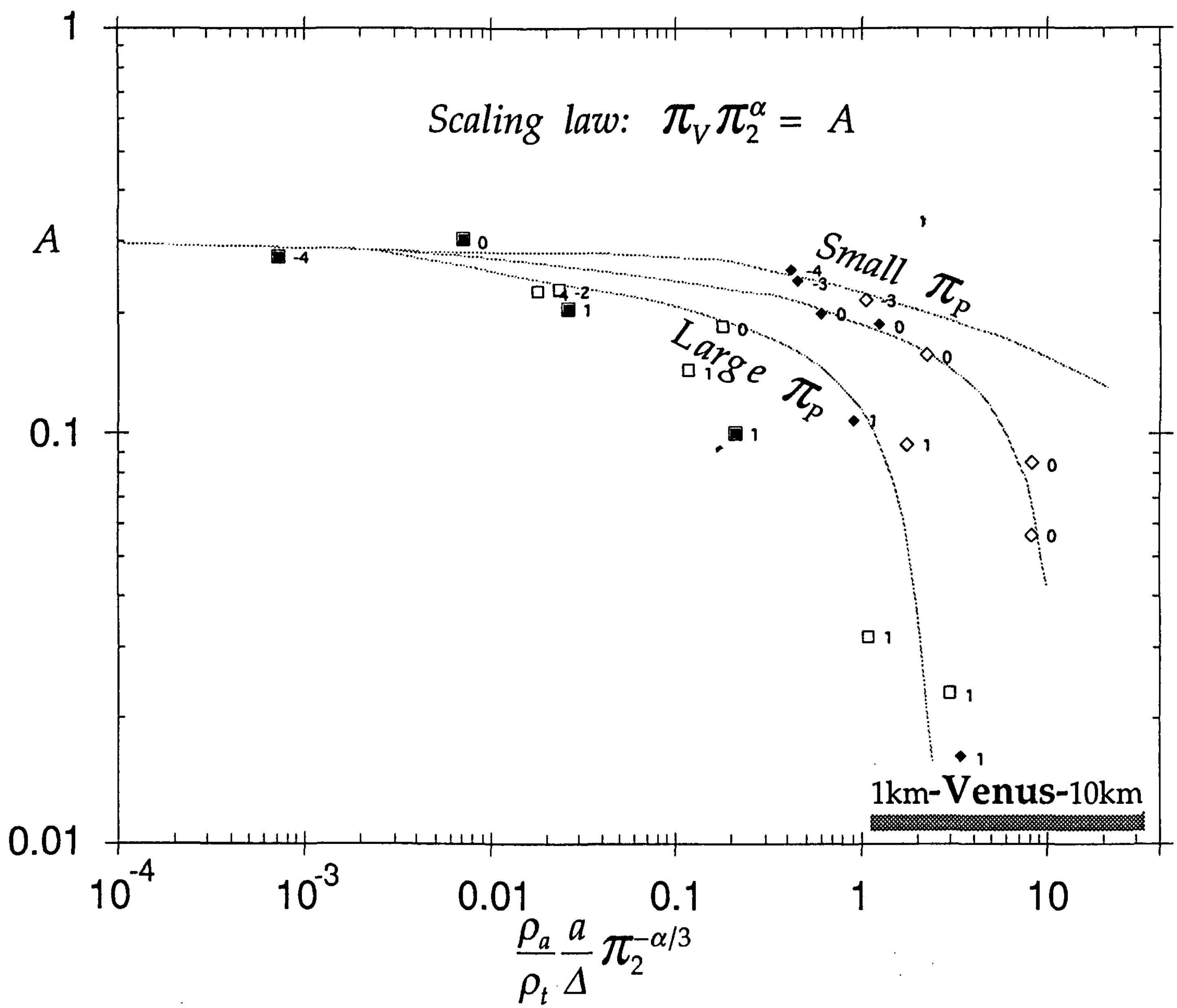
75% volume

Pressure effect on crater size



PRECEDING PAGE BLANK NOT FILMED

Density (drag) effect on crater size



Approach for Phase 2
(currently underway)

- **Calculation of coupled impact, cratering, ejecta, and airblast**
  — Determine partitioning of impactor kinetic energy into airblast
  — Track airblast out to times and ranges beyond crater

- **Assume impactor reaches surface intact**

- **Treat body as "swarm" of various size "particles"**
  — EOS includes hydrodynamic pressures under compression

- **Calculate momentum transfer to ground using ALE logic**
  — Formation of impact crater and ejecta

- **EOS includes high-pressure vaporization of impactor and ground**
  — Vaporized material available for airblast

Summary

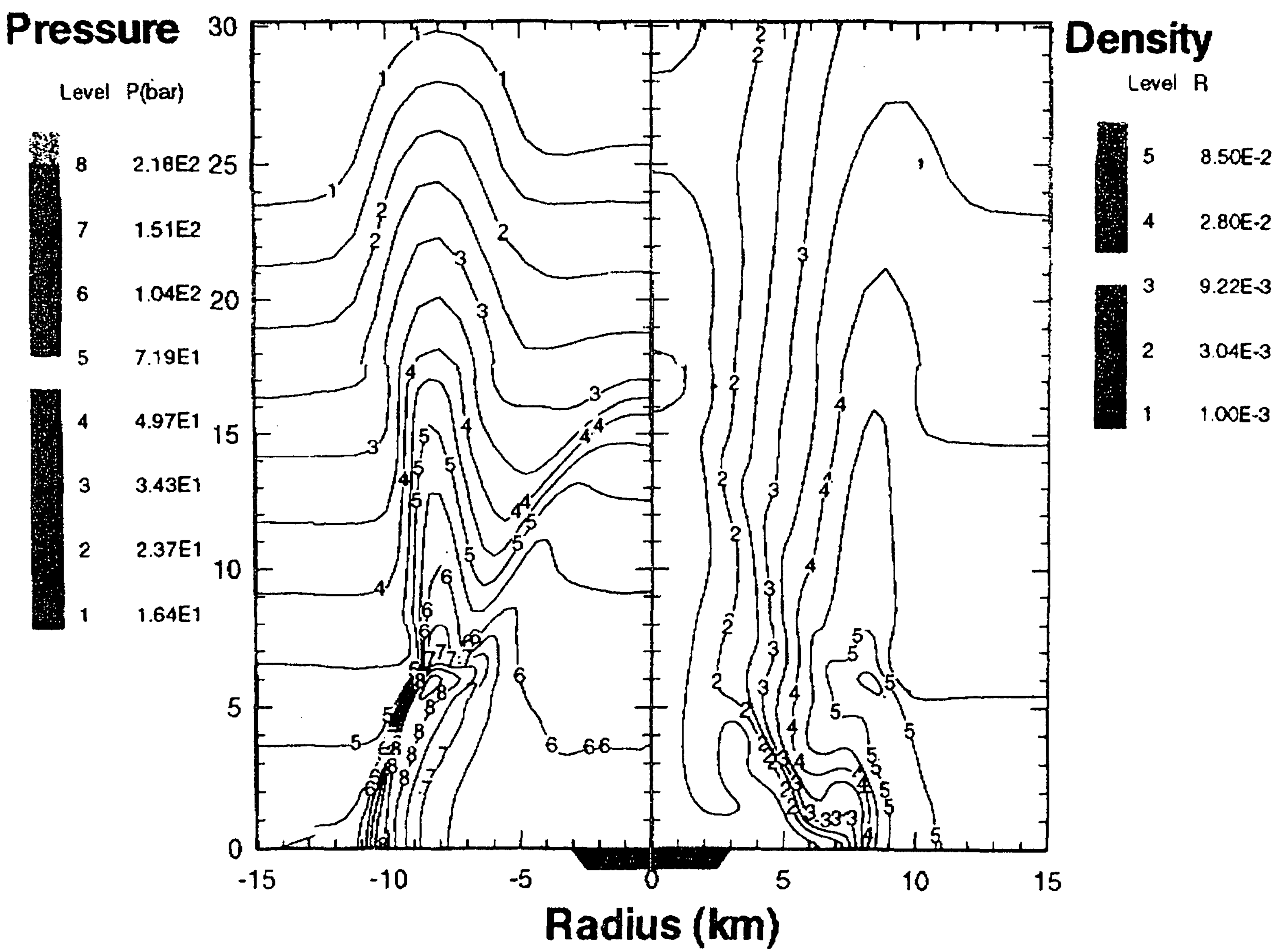
- This is a hard problem, all effects lead to smaller craters!
    1) Increased pressure/drag on crater formation
    2) Slowdown of impactor due to entry drag
    3) Breakup of impactor due to pressure distribution
- Progress has been made in isolating variables.
- Preliminary forms for scaling laws have been developed.
- Improved calculations for transient pressure and density underway.
- Shooting light gas gun into high pressure chamber demonstrated.
- Equivalent explosive experiments provide supporting data.
- Objective is to obtain <u>useful scaling relationships</u> for:

    <u>Crater formation when atmospheric effects are important.</u>

PAGE 01 PHYSICOMP 8182223244 21:39 03/09/1995

1-km Diameter Impactor into Venus

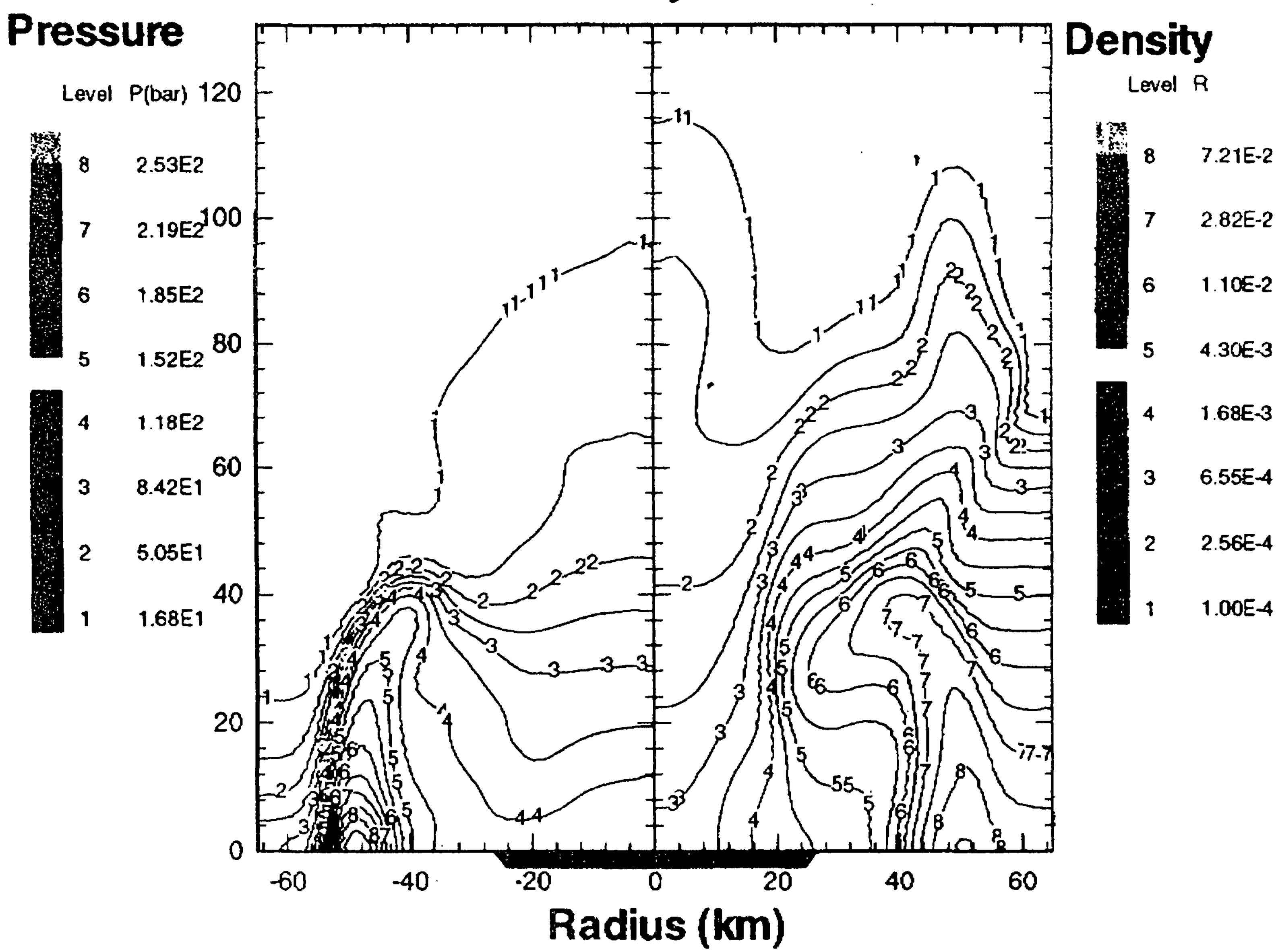
20 km/s Initial Velocity time = 9 sec



[redacted]

10-km Diameter Impactor into Venus

20 km/s Initial Velocity time = 20 sec



Target EOS for Phase II

Quartz

• Initial Density	2.5 gm/cm^3
• Air-filled void volume	8%
• Initial Bulk Modulus	0.45 Mb
• Maximum Bulk Modulus	0.75
• Vaporization Activation Energy	$1.7 * 10^{10}$ ergs/gm
• Initial Shear Modulus	0.173 Mb
• von Mises Limit in Compression	0.017 Mb
• Cohesion	50 bars
• Slope of Mohr Coulomb Surface	0.75
• Poisson's Ratio	0.33

8182223244 PHYSICOMP PAGE