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" Sixth Workshop on Non-Linear Dynamics and Earthquake Prediction"

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Earthquake Scaling and the Strength of Seismogenic Faults

Stephen A. Miller

Geophysics Institute
ETH-Zurich, Switzerland

Lecture I: The dynamical influence of fluids on seismicity and faulting

- Rock and fluid mechanics
- Dislocations and brittle faulting
- Stress transfer models
- The hydraulics of fault zones
- Coupling fluid flow to large scale tectonics
- Earthquakes as a coupled shear stress, high pore pressure dynamical system
- The properties of large model earthquakes

Lecture II: Earthquake scaling and the strength of seismogenic faults

- **Earthquake scaling: Small earthquakes**
- **Earthquake scaling: Large earthquakes**
- **Pore pressure as a fundamental scaling parameter**
- **Application of result to global earthquake catalogs**
- **Can pore pressures be inferred from earthquake rupture properties**

Lecture III: Neotectonics and earthquake generation along complex fault systems

- The North Anatolian Fault Zone
- The San Andreas Fault System
- Building a forward model of the earthquake process
- Fault Interaction

Earthquake scaling

$M_0 = \mu L W \bar{u}$

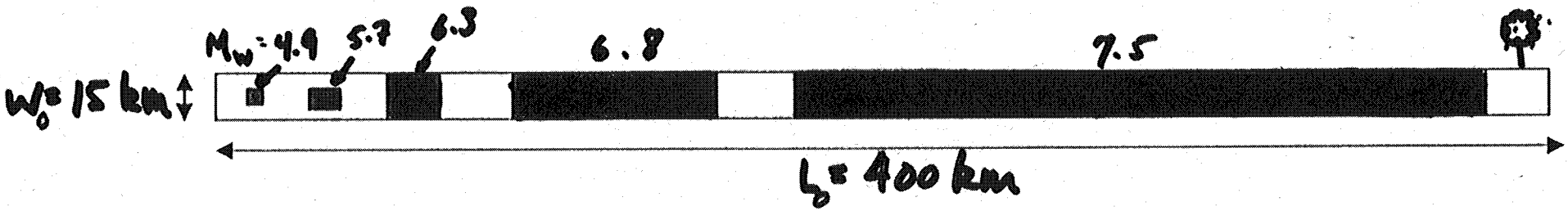
μ = Shear Modulus
L = Rupture Length
W = Rupture Width
$\bar{u}$ = Average Slip
$\Delta\tau = C\mu\left(\frac{\bar{u}}{\Lambda}\right)$
Λ = Scale length

$\frac{L}{W_0} < 1$; SMALL

$L \sim W$ and $\Delta\tau$ a constant

$\Rightarrow \bar{u}(L)$

$\Rightarrow \boxed{M_0} \propto L W \bar{u}(L) \propto \boxed{L^3}$



LARGE ; $\frac{L}{W_0} > 1$

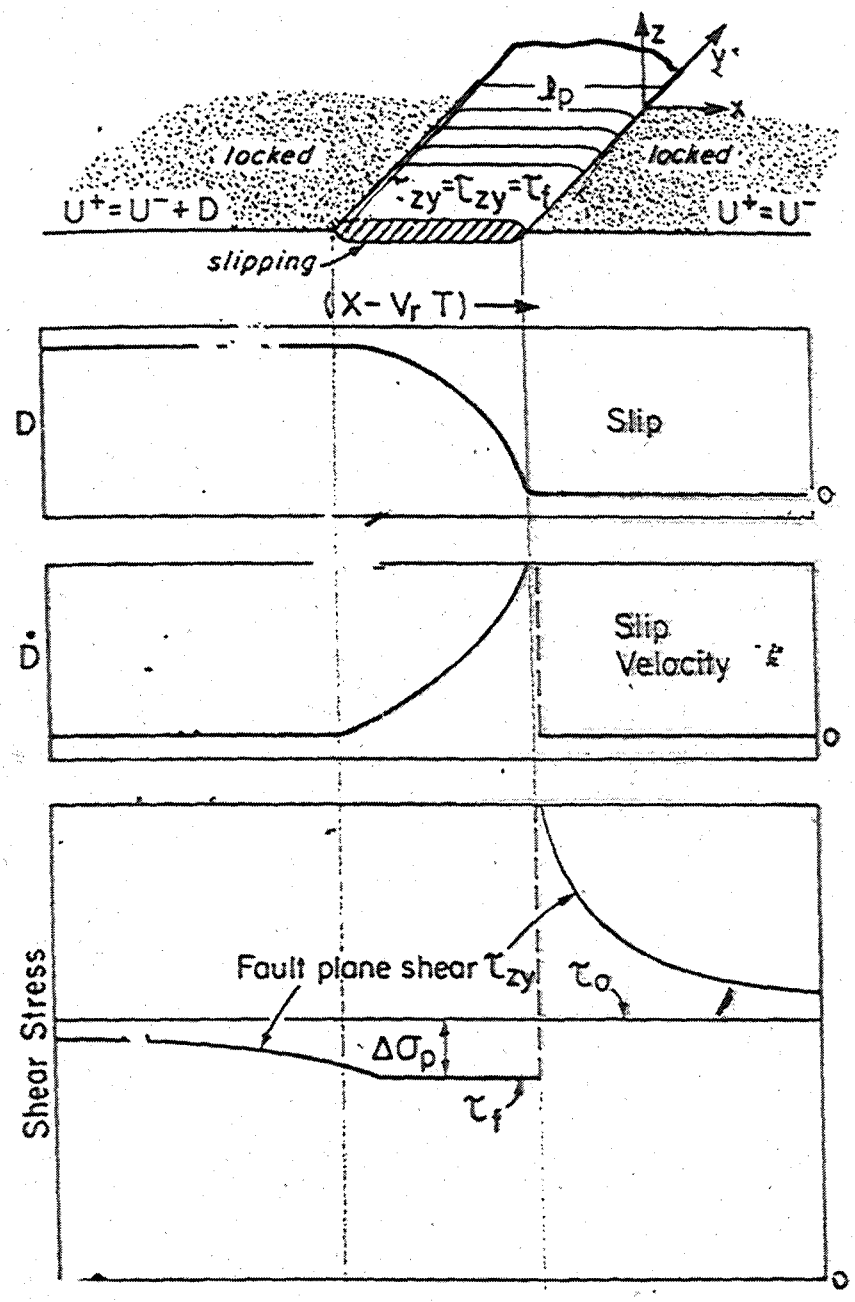
W = const.

$\Delta\tau \sim$ constant

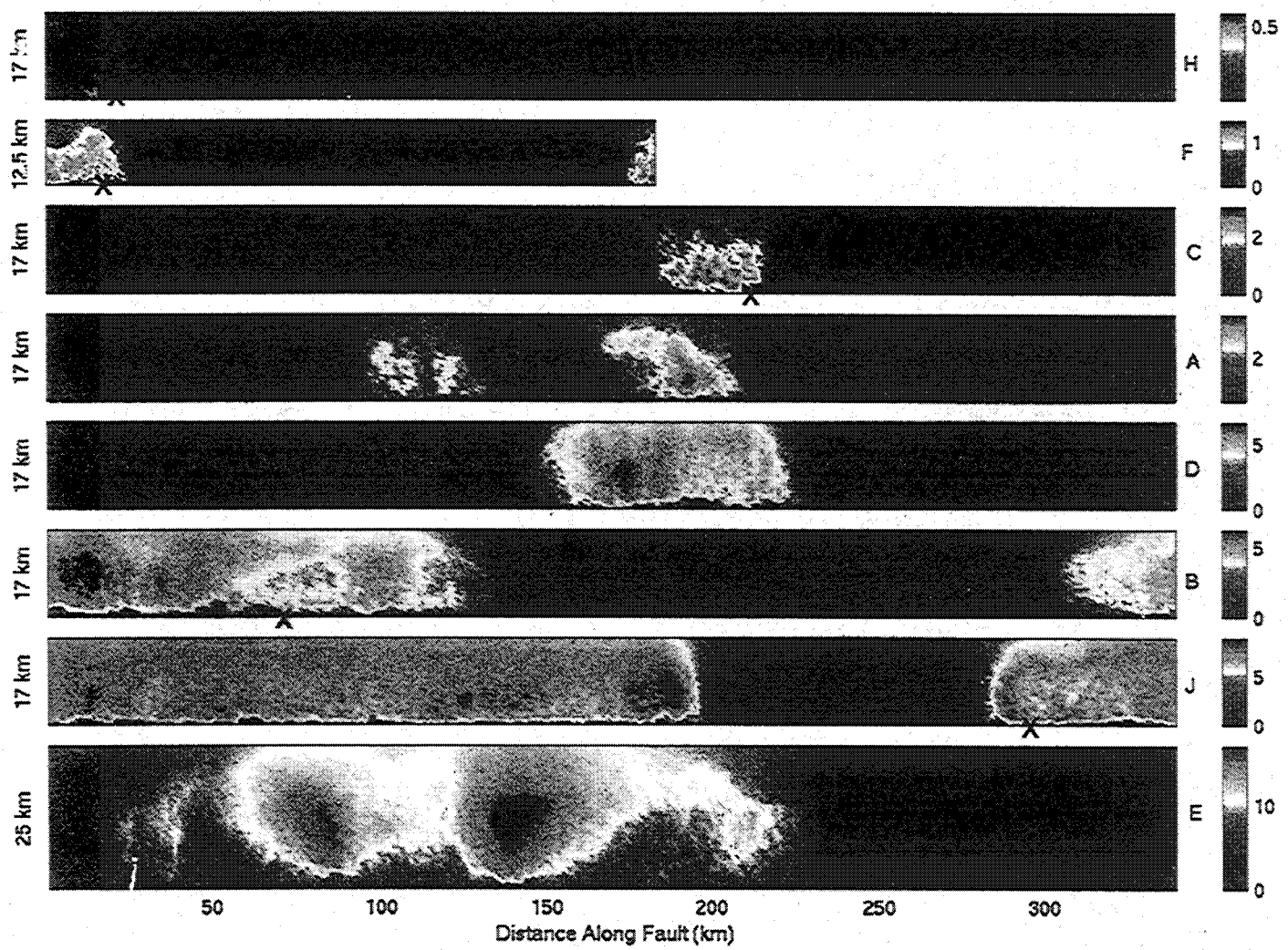
if $\bar{u}(L) \rightarrow M_0 \propto L W_0 \bar{u}(L) \propto L^2 \rightarrow$ L-model

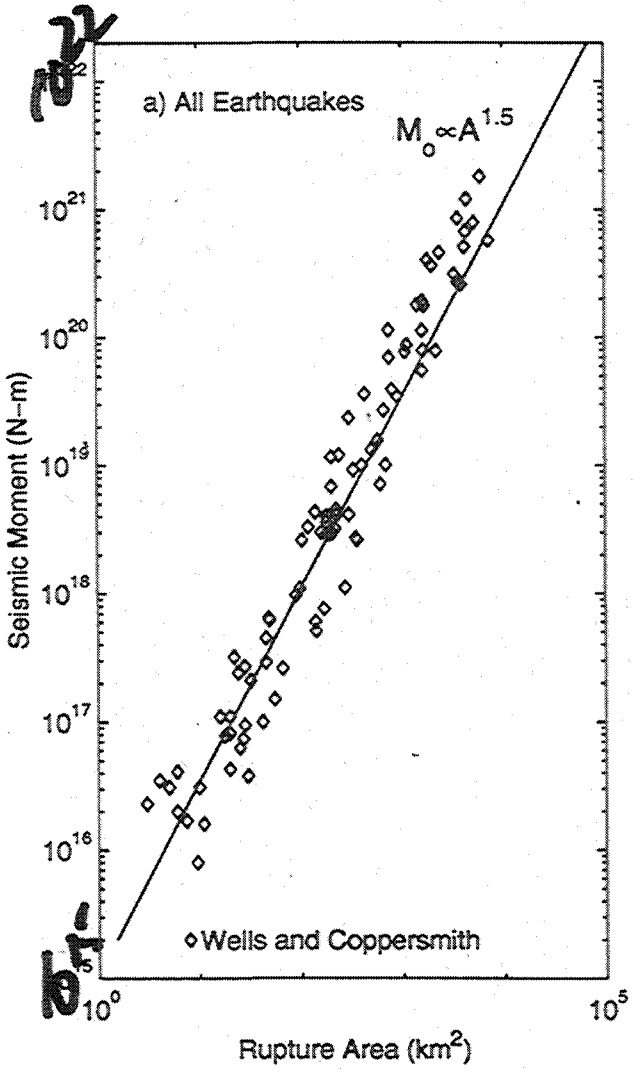
if $\bar{u} \neq \bar{u}(L) \Rightarrow M_0 \propto L W_0 \bar{u} \propto L \rightarrow$ W-model

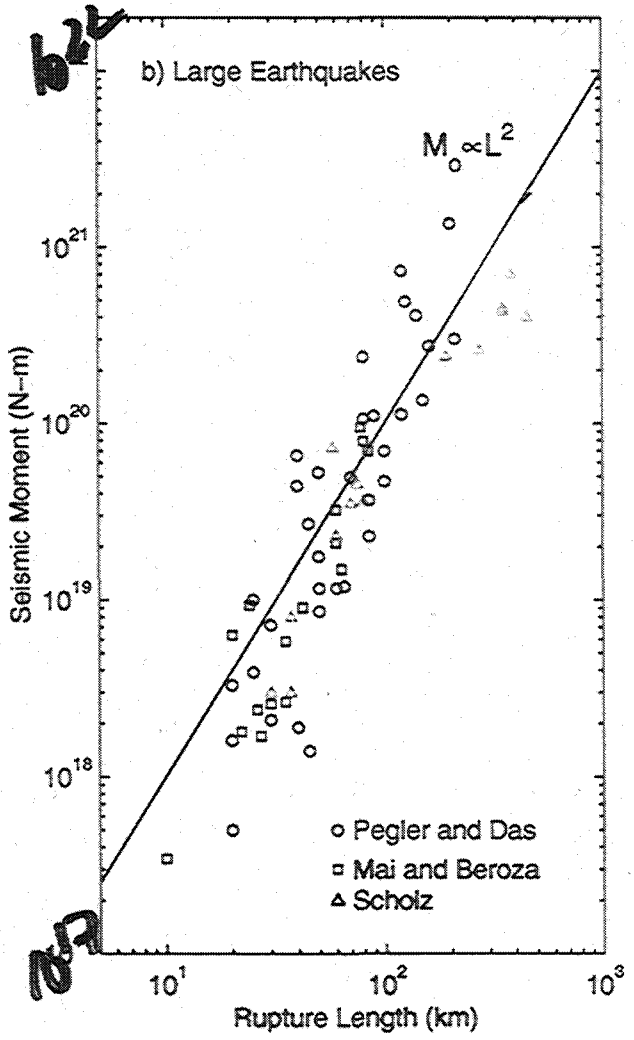
SELF-HEALING PULSES OF SLIP IN EARTHQUAKE RUPTURE



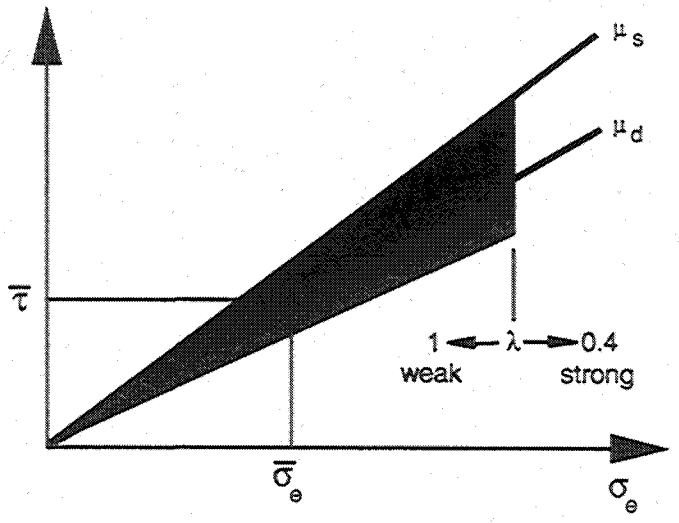
Heaton (90)


17 km
12.5 km
17 km
17 km
17 km
17 km
17 km
25 km
H
F
C
A
D
B
J
E
0.5
1
0
2
0
2
5
0
5
0
5
0
10
0
50
100
150
200
250
300
Distance Along Fault (km)

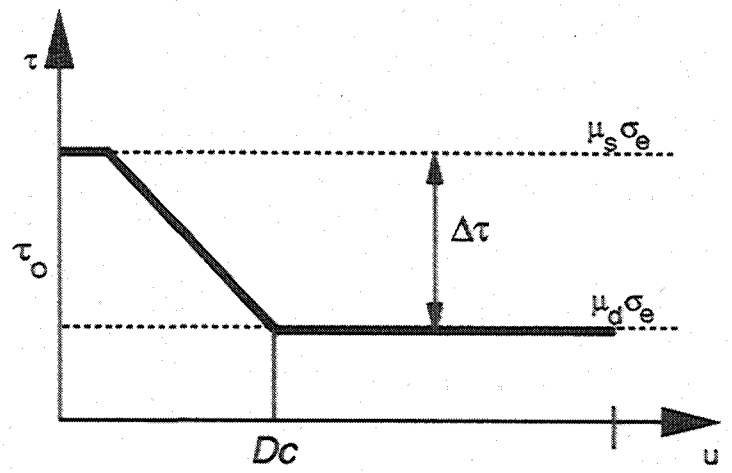

a) All Earthquakes
$M_o \propto A^{1.5}$
Seismic Moment (N-m)
Rupture Area (km^2)
Wells and Coppersmith


b) Large Earthquakes
$M_o \propto L^2$
Seismic Moment (N-m)
Rupture Length (km)
Pegler and Das
Mai and Beroza
Scholz

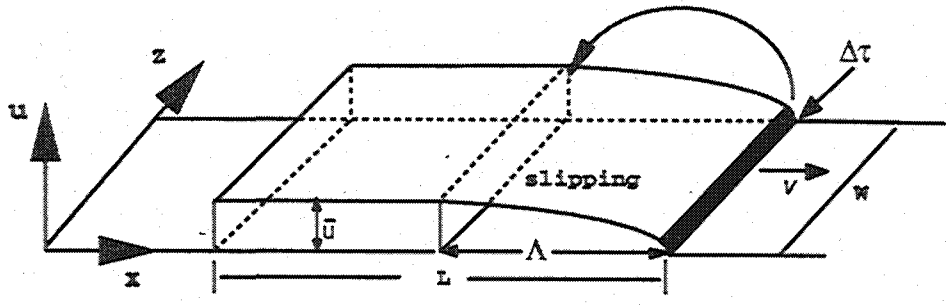
a)


μ_s
μ_d
$\bar{\tau}$
1 ← λ → 0.4
weak
strong
$\bar{\sigma}_e$
σ_e

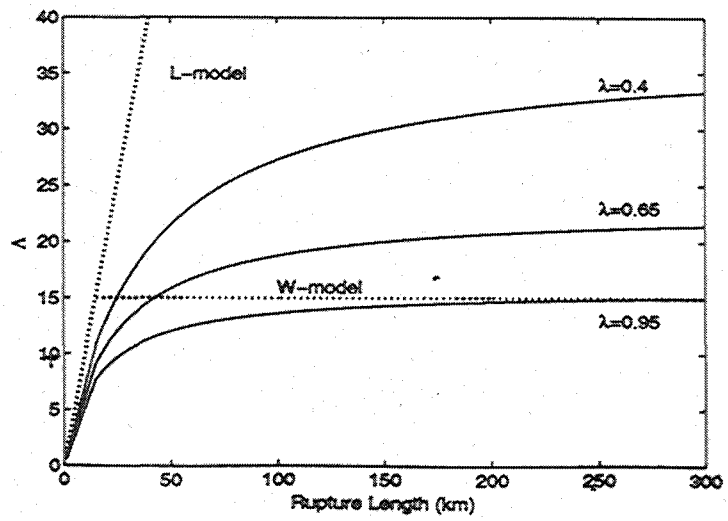
b)

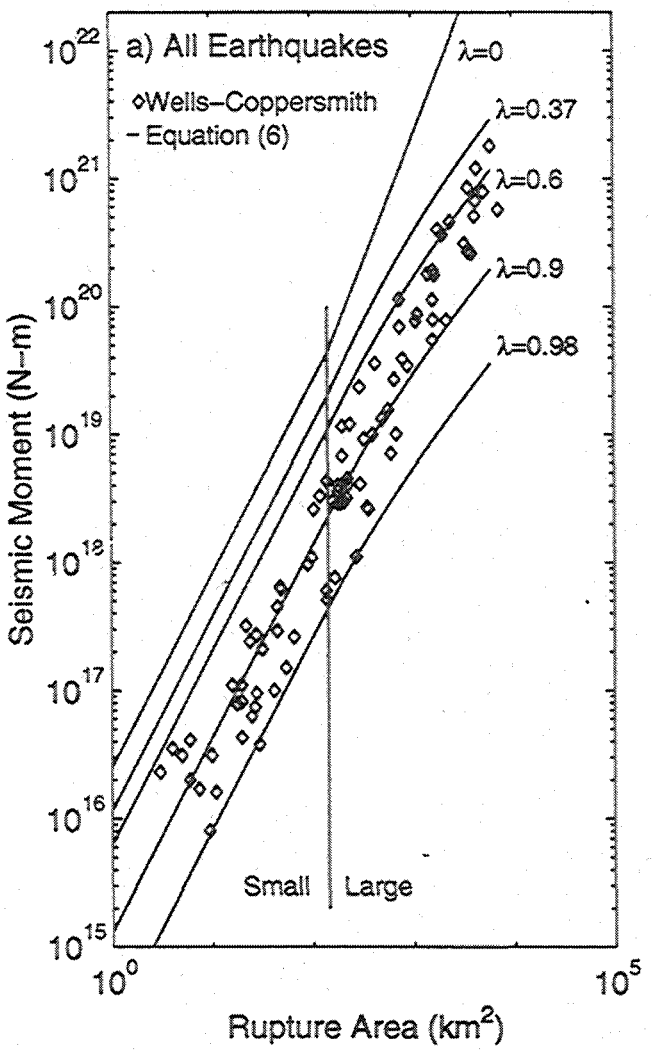

τ
$\mu_s\sigma_e$
$\Delta\tau$
τ_o
$\mu_d\sigma_e$
Dc
u

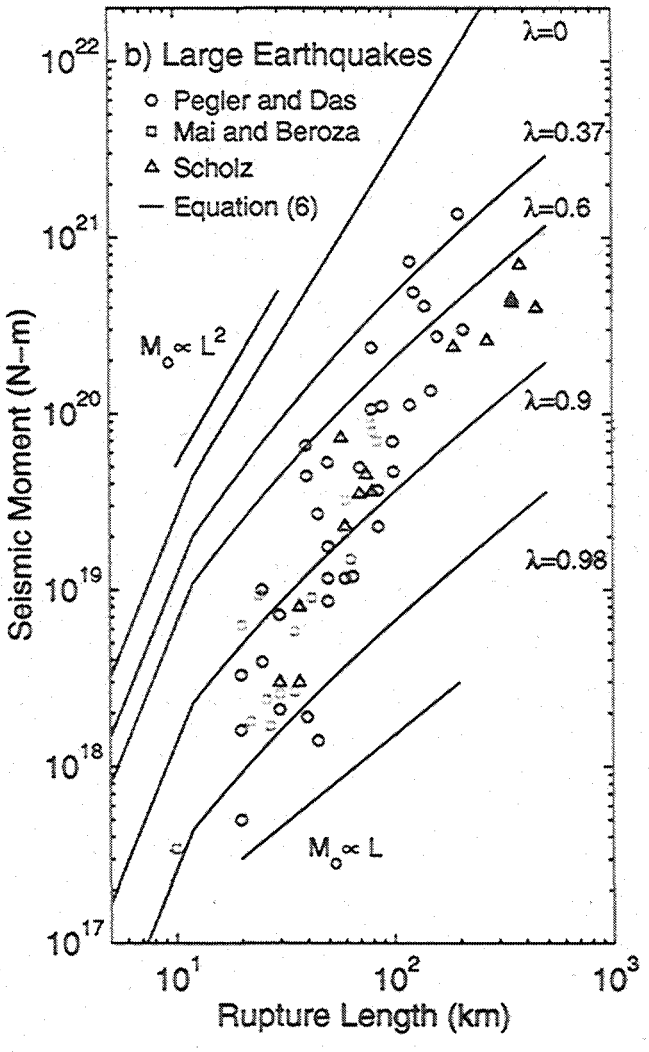
c)

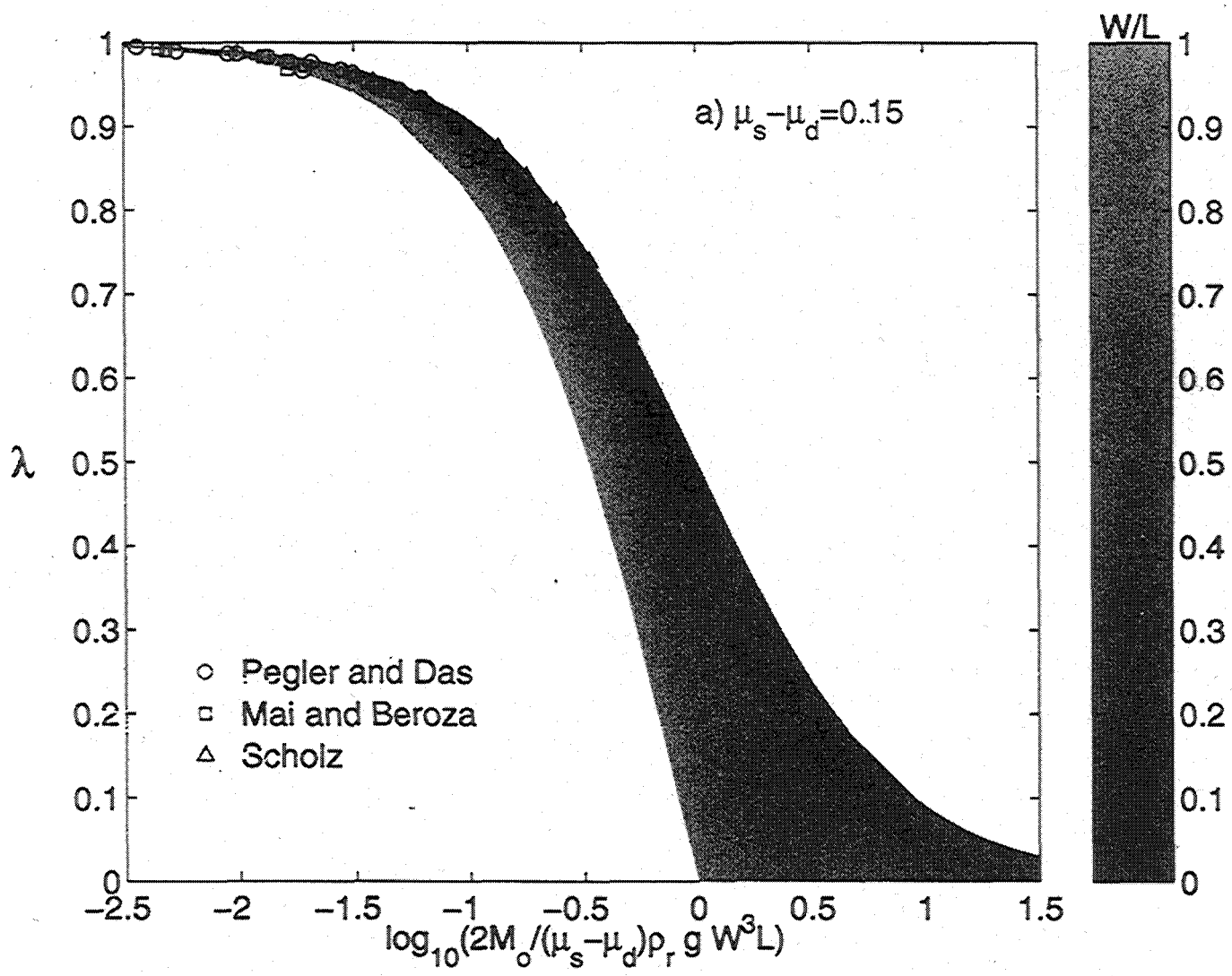

z
u
Δτ
slipping
v
W
ū
Λ
x
L

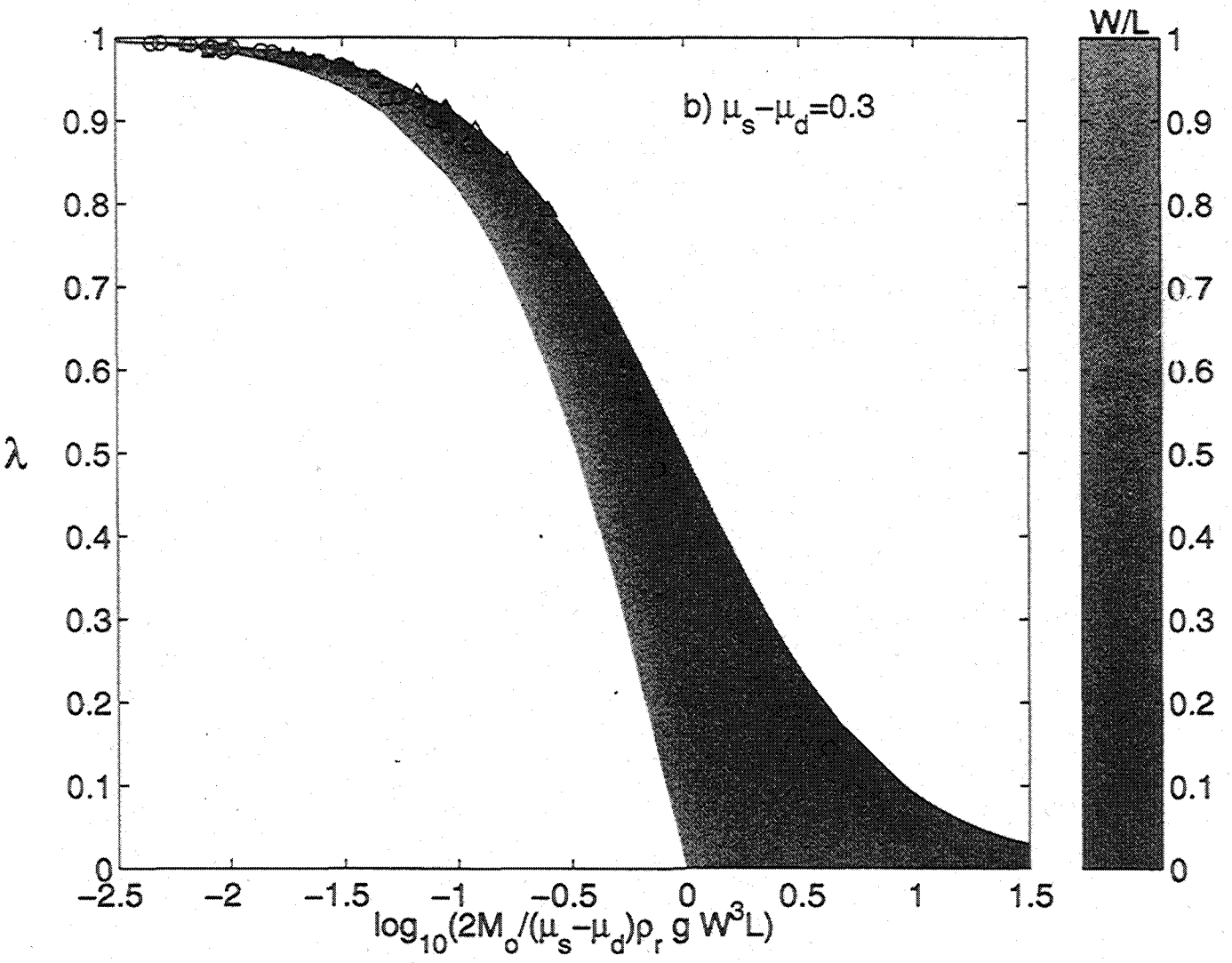
d)

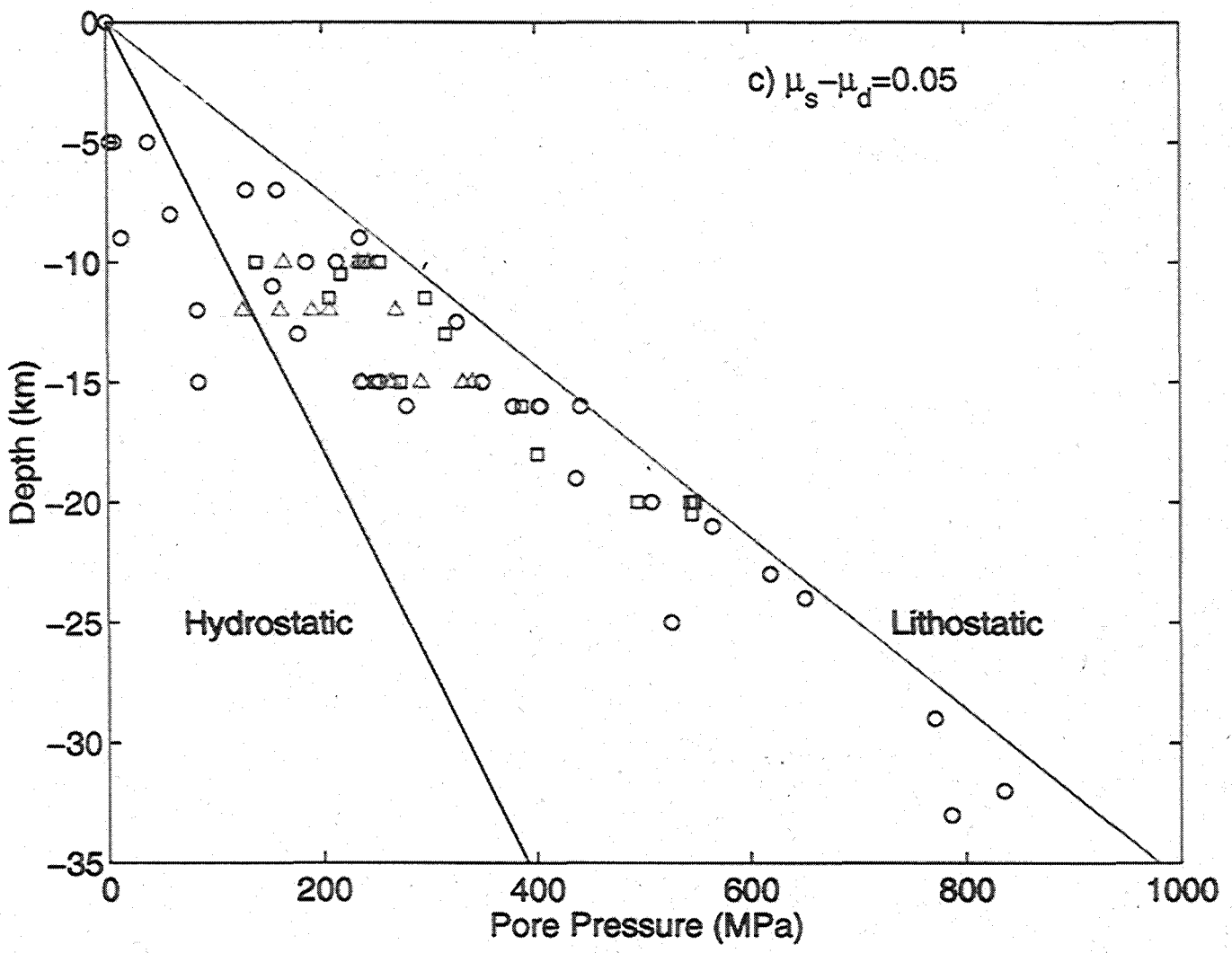

L-model
λ=0.4
λ=0.65
W-model
λ=0.95
Λ
Rupture Length (km)
0
5
10
15
20
25
30
35
40
50
100
150
200
250
300

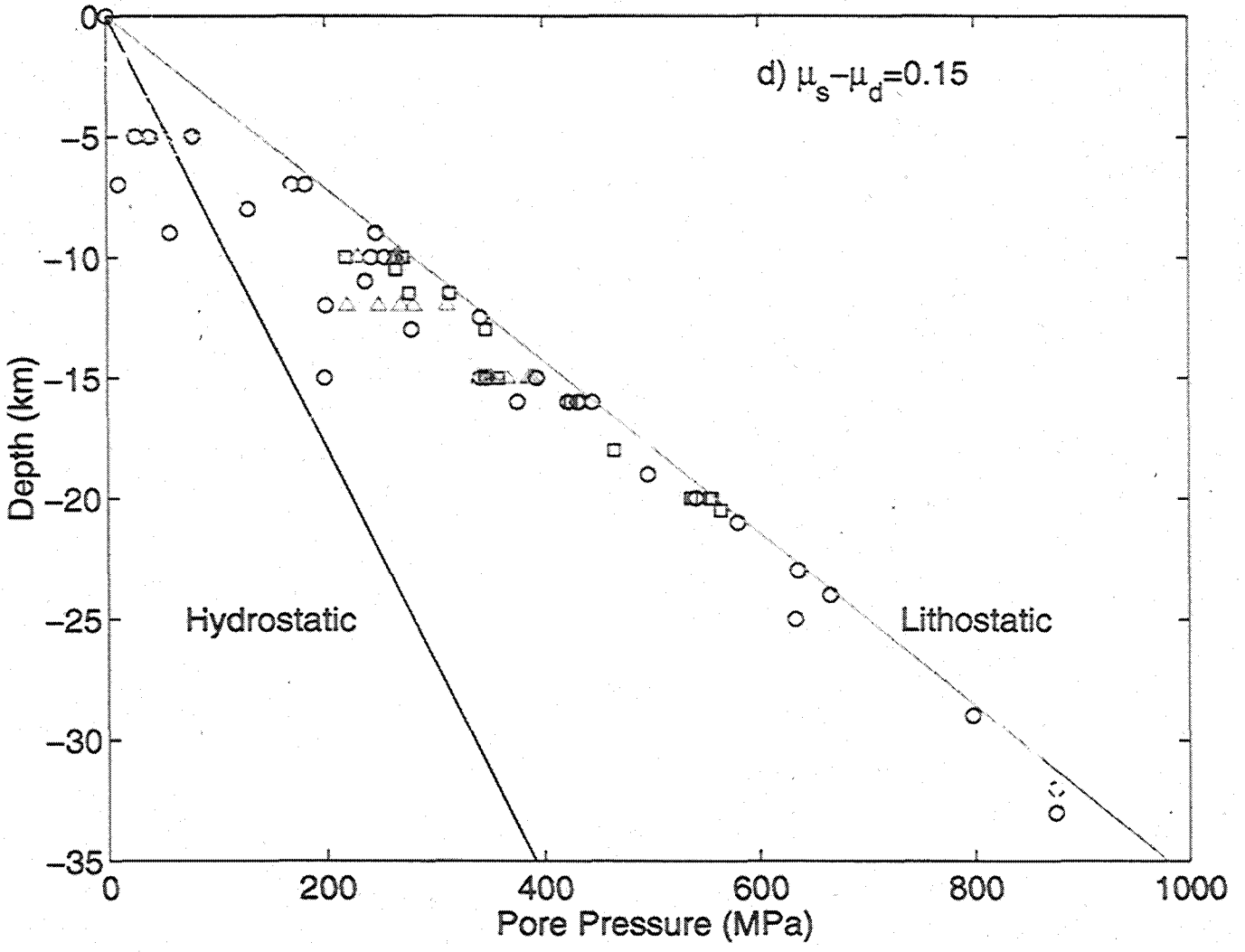

a) All Earthquakes
λ=0
λ=0.37
λ=0.6
λ=0.9
λ=0.98
◇Wells–Coppersmith
– Equation (6)
Small
Large
Seismic Moment (N–m)
Rupture Area (km²)
10²²
10²¹
10²⁰
10¹⁹
10¹⁸
10¹⁷
10¹⁶
10¹⁵
10⁰
10⁵

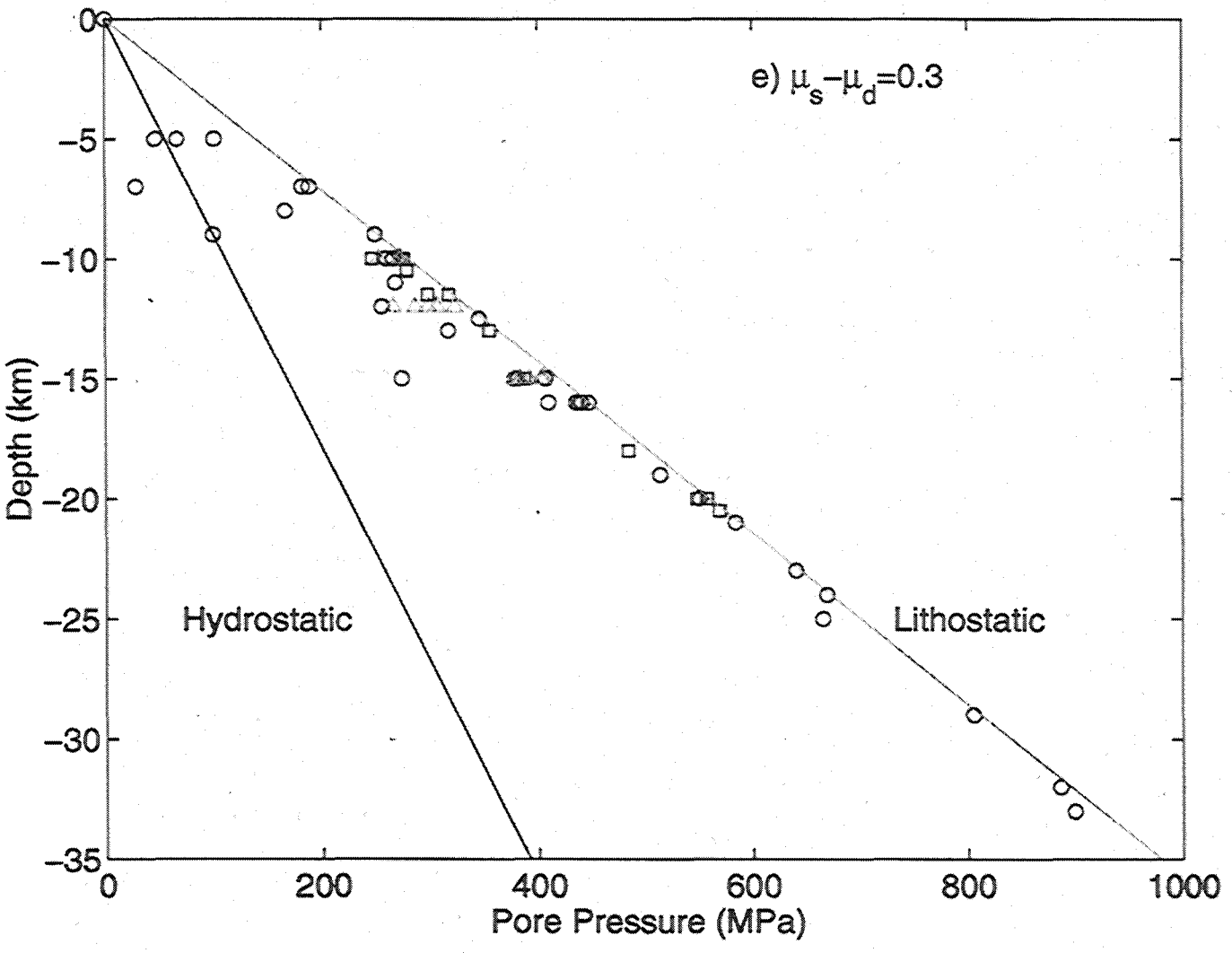

b) Large Earthquakes
λ=0
λ=0.37
λ=0.6
λ=0.9
λ=0.98
○ Pegler and Das
□ Mai and Beroza
△ Scholz
— Equation (6)
M₀∝ L²
M₀∝ L
Seismic Moment (N–m)
Rupture Length (km)
10²²
10²¹
10²⁰
10¹⁹
10¹⁸
10¹⁷
10¹
10²
10³

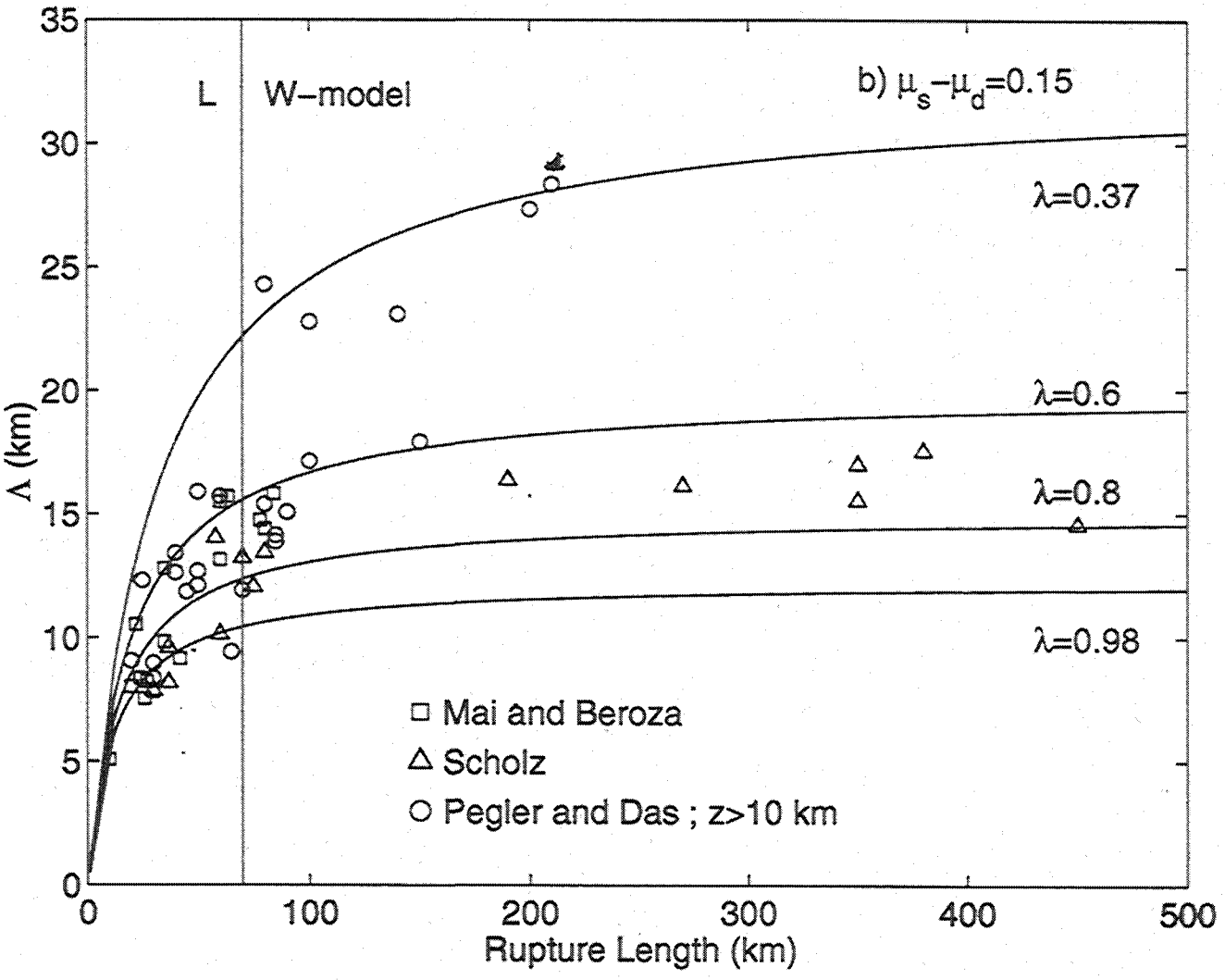

a) $\mu_s - \mu_d = 0.15$
Pegler and Das
Mai and Beroza
Scholz
λ
$\log_{10}(2M_o/(\mu_s - \mu_d)\rho_r g W^3 L)$
W/L
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
−2.5
−2
−1.5
−1
−0.5
0
0.5
1
1.5

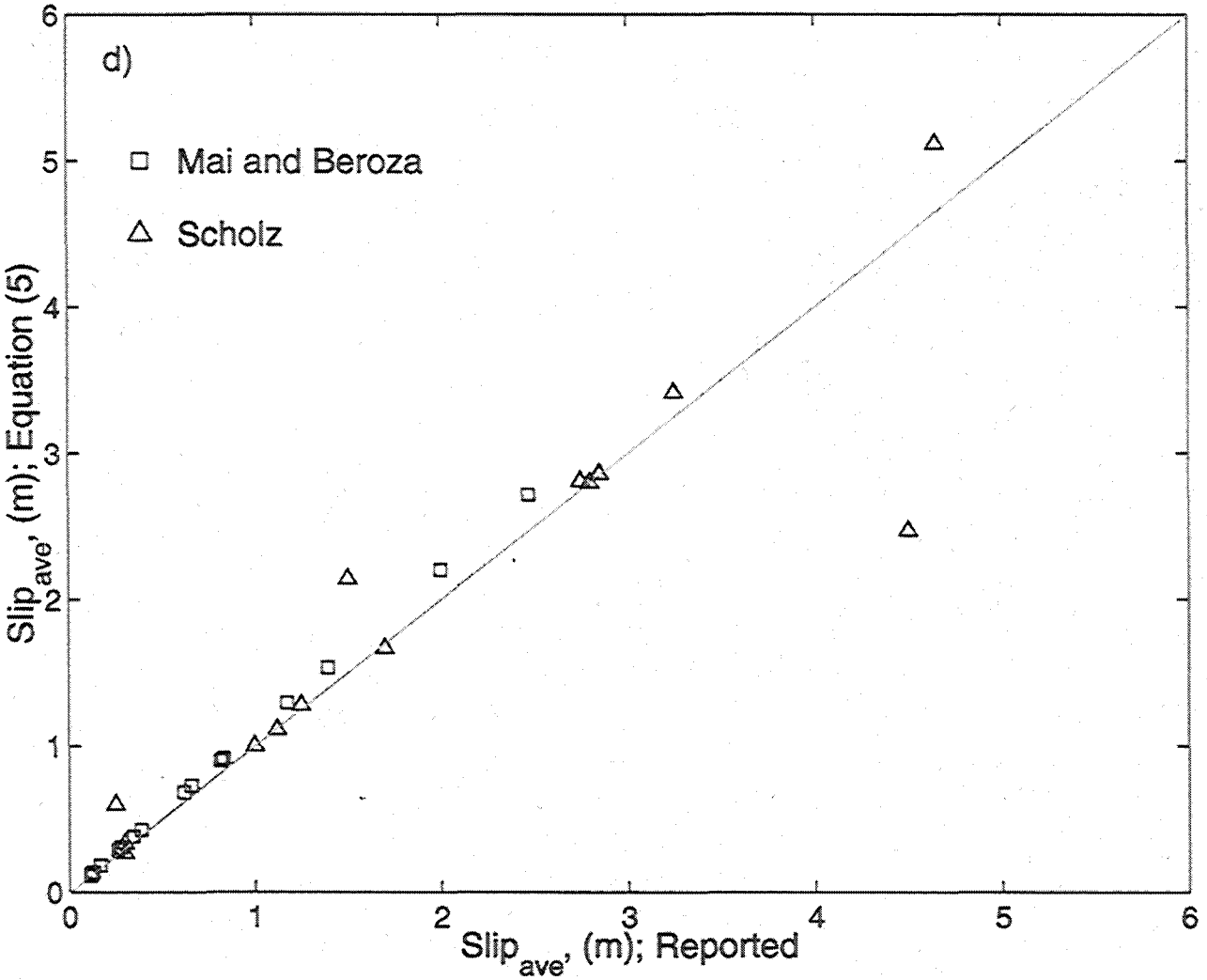

b) $\mu_s - \mu_d = 0.3$
λ
$\log_{10}(2M_o/(\mu_s - \mu_d)\rho_r g W^3 L)$
W/L
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
−2.5
−2
−1.5
−1
−0.5
0
0.5
1
1.5

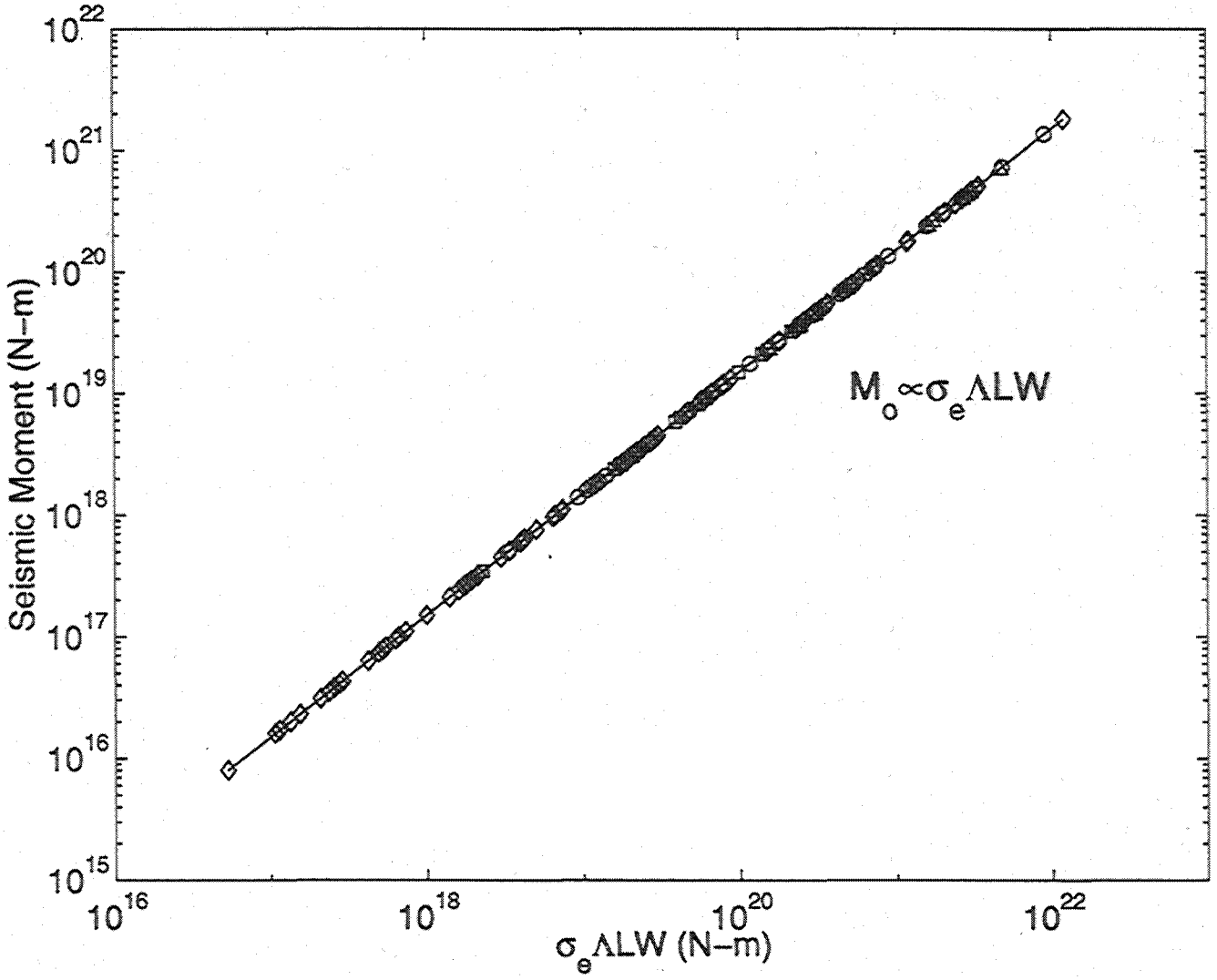

c) $\mu_s - \mu_d = 0.05$
Depth (km)
Pore Pressure (MPa)
Hydrostatic
Lithostatic
0
−5
−10
−15
−20
−25
−30
−35
0
200
400
600
800
1000

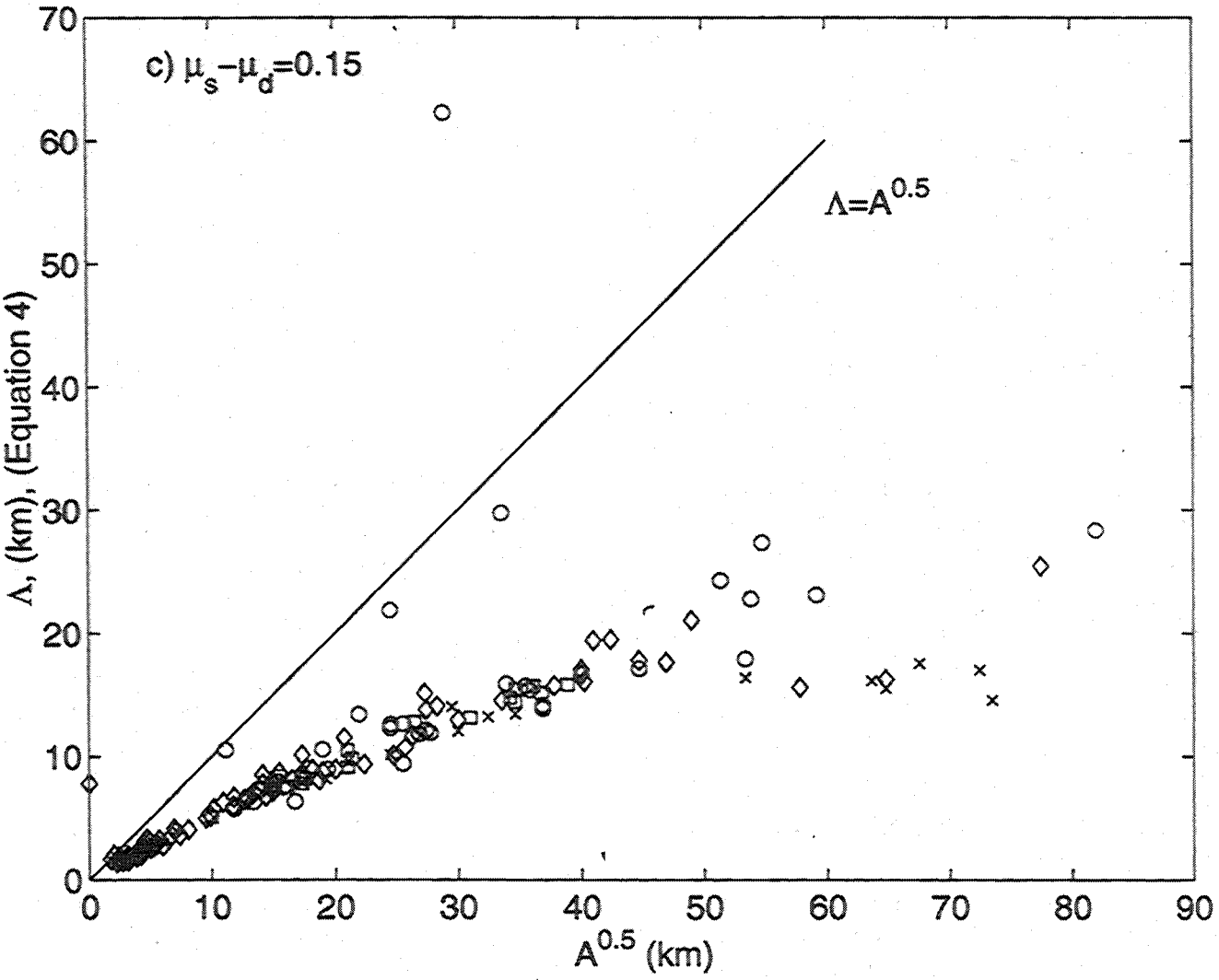

d) $\mu_s - \mu_d = 0.15$
Depth (km)
0
−5
−10
−15
−20
−25
−30
−35
Hydrostatic
Lithostatic
0
200
400
600
800
1000
Pore Pressure (MPa)


e) $\mu_s - \mu_d = 0.3$
Depth (km)
Pore Pressure (MPa)
Hydrostatic
Lithostatic
0
−5
−10
−15
−20
−25
−30
−35
0
200
400
600
800
1000


L
W-model
b) $\mu_s - \mu_d = 0.15$
λ=0.37
λ=0.6
λ=0.8
λ=0.98
Mai and Beroza
Scholz
Pegler and Das ; z>10 km
Λ (km)
Rupture Length (km)
0
5
10
15
20
25
30
35
0
100
200
300
400
500


d)
Mai and Beroza
Scholz
Slip$_{ave}$, (m); Equation (5)
Slip$_{ave}$, (m); Reported
0
1
2
3
4
5
6


Seismic Moment (N–m)
10^{22}
10^{21}
10^{20}
10^{19}
10^{18}
10^{17}
10^{16}
10^{15}
10^{16}
10^{18}
10^{20}
10^{22}
$\sigma_e \Lambda LW$ (N–m)
$M_o \propto \sigma_e \Lambda LW$


c) $\mu_s - \mu_d = 0.15$
$\Lambda = A^{0.5}$
Λ, (km), (Equation 4)
$A^{0.5}$ (km)
0
10
20
30
40
50
60
70
80
90