



The Abdus Salam
International Centre for Theoretical Physics



Advanced School on Scaling Laws in Geophysics: Mechanical and Thermal Processes in Geodynamics

Organizer(s): Directors: A. Aoudia, P. Molnar, G. Houseman, C. Jaupart, M. Manga
Trieste - Italy, 23 May 2011 - 3 June 2011

Venue: Adriatico Guest House Kastler Lecture Hall

Programme

Registration and Reception (Room:Adriatico Guest House - Kastler Lecture Hall Area (Lower Level 1)) (Sunday)

22 May 2011

18:00 - 19:00 **REGISTRATION**

19:00 - 21:00 (Room: Adriatico Guest House (Terrace))
RECEPTION - GET TOGETHER

Overview and Basic Continuum Mechanics (Room:Adriatico Guest House Kastler Lecture Hall)

23 May 2011

09:00 - 10:30 **M. Manga, P. Molnar** / *Univ. of California, USA , Univ. of Colorado at Boulder, USA*
What are scaling laws, why are they important in geodynamics, and what problems in geophysics make them attractive.

10:30 - 11:00 (Room: Adriatico Guest House (Terrace))
--- Coffee Break ---

11:00 - 12:00 **G. Houseman** / *University of Leeds, UK*
Stress and strain, and basic isostasy (statics).

12:00 - 12:30 **P. Molnar** / *Univ. of Colorado at Boulder, USA*
Simple problems of isostasy

12:30 - 14:00 (Room: Adriatico Guest House Cafeteria)
--- Lunch Break ---

13:30 - 14:30 (Room: Finance Office, Enrico Fermi Building)
ADMINISTRATIVE FORMALITIES

Why we care: mantle dynamics (Room:Adriatico Guest House Kastler Lecture Hall)

23 May 2011

14:30 - 16:00 **M. Manga / Univ. of California, Berkeley, USA**
Stokes equation, equation of continuity, and constitutive laws (both Newtonian, and non-Newtonian with underlying physics).

16:00 - 16:30 (Room: Adriatico Guest House (Terrace))
--- Coffee Break ---

16:30 - 18:00 **P. Molnar, G. Houseman / Univ. of Colorado at Boulder, USA Univ. of Leeds, UK**
Some simple problems to relate stress and strain and illustrate constitutive laws, such as enhanced localization with non-Newtonian viscosity, with channel flow as an example. Exercises illustrating channel flow: Couette flow: problems, non-Newtonian material, exponential viscosity

Gravitational potential energy per unit area (GPE) and the thin viscous sheet (Room:Adriatico Guest House Kastler Lecture Hall)

24 May 2011

09:00 - 10:00 **P. Molnar / Univ. of Colorado at Boulder, USA**
Derivation of GPE. 2D stress balance for different crustal structure/boundary conditions

10:00 - 10:30 --- Coffee break ---

10:30 - 12:00 **G. Houseman / Univ. of Leeds, UK**
Derivation of thin viscous sheet equations

12:00 - 12:30 **G. Houseman, P. Molnar / Univ. of Leeds, UK, Univ. of Colorado at Boulder, USA**
Scaling of stress differences to elevations (in isostasy), and simple problems illustrating force per unit length

12:30 - 14:00 (Room: Adriatico Guest House Cafeteria)
--- Lunch Break ---

14:00 - 16:00 **G. Houseman / Univ. of Leeds, UK**
Diagnostics of thin sheet deformation: matching gradients in strain-rates to gradients in GPE, and faulting response. Case studies: Tibet, Aegean and Indian Ocean.

16:00 - 16:30 (Room: Adriatico Guest House (Terrace))
--- Coffee Break ---

16:30 - 17:30 **G. Houseman / Univ. of Leeds, UK**
Scaling of areal extent of deformation to dimensions of boundaries and to n (England, Houseman, and Sonder, 1985), plus dependence on Ar . Exercises on simple boundary-driven deformation problems using basic solutions. Dependence on the Argand number, Ar , and the exponent n .

Rayleigh-Taylor instability (Room:Adriatico Guest House Kastler Lecture Hall)

25 May 2011

- 09:00 - 10:00** **G. Houseman / Univ. of Leeds, UK**
Derivation of basic equation for growth rate. Example of instability
- 10:00 - 10:30** (Room: Adriatico Guest House (Terrace))
--- Coffee Break ---
- 10:30 - 11:30** **G. Houseman / Univ. of Leeds, UK**
Growth rate as a function of wavenumber, dependence on boundary conditions, eigenfunctions
- 11:30 - 12:30** **Examples using Houseman s code sybil to examine exponential form of blobs and thinning using runs already carried out. Derive the growth rate for a simple case. (For instance, 2 half-spaces with constant, different density, and exponentially decreasing viscosity), Scaling of growth rate to various parameters (density, g, thickness, and viscosity).**
- 12:30 - 14:00** (Room: Adriatico Guest House Cafeteria)
--- Lunch Break ---
- 14:00 - 14:30** **G. Houseman / Univ. of Leeds, UK**
Rayleigh-Taylor instability, effects of non-Newtonian viscosity. Derivation of the dependence of growth rate on n.
- 14:30 - 15:30** **G. Houseman / Univ. of Leeds, UK**
Examples using sybil to examine the time dependence of growth: exponential for $n = 1$, and super-exponential with $n > 1$ Scaling of growth rate to n.
- 15:30 - 16:00** (Room: Adriatico Guest House (Terrace))
--- Coffee Break ---
- 16:30 - 17:30** (Room: Leonardo da Vinci Building Main Lecture Hall)
P. Molnar / Univ. of Colorado at Boulder, USA
ICTP COLLOQUIUM: Mantle dynamics and the rise and fall of mountain belts

Stokes flow, dynamic topography, and introduction of thermal processes (Room:Adriatico Guest House Kastler Lecture Hall)

26 May 2011

- 09:00 - 10:00** **P. Molnar / Univ. of Colorado at Boulder, USA**
Stokes flow and dynamic topography Stokes problem of a sinking sphere
- 10:00 - 10:30** (Room: Adriatico Guest House (Terrace))
--- Coffee Break ---
- 10:30 - 11:30** **P. Molnar / Univ. of Colorado at Boulder, USA**
Deflection of the surface above a sinking sphere and associated gravity anomalies and geoid. [Morgan, 1965]
- 11:30 - 12:30** **G. Houseman / Univ. of Leeds, UK**
Basil/sybil exercise with a sinking sphere or cylinder
- 12:30 - 14:00** (Room: Adriatico Guest House Cafeteria)
--- Lunch Break ---

Introduction of thermal processes (Room:Adriatico Guest House Kastler Lecture Hall)

26 May 2011

- 14:00 - 15:00** **M. Manga / Univ. of California, Berkeley, USA**
Derivation of the basic heat transfer equation and heating or cooling by diffusion
- 15:00 - 15:30** (Room: Adriatico Guest House (Terrace))
--- Coffee Break ---
- 15:30 - 16:30** **M. Manga / Univ. of California, Berkeley, USA**
Examples of a cooling lithosphere: both cooling plate and cooling half-space, comparison of different boundary conditions (fixed temperature and fixed heat flux).
- 16:30 - 17:00** **M. Manga / Univ. of California, Berkeley, USA**
Solidification Scaling of time and depth in thermal diffusion
- 17:00 - 17:30** **P. Molnar / Univ. of Colorado at Boulder, USA**
Molnar and England's S in thrust faulting

Turbulence, processes involved in volcanoes, introduction to convection, and mixing (Room:Adriatico Guest House Kastler Lecture Hall)

27 May 2011

- 09:00 - 10:00** **J. Niemala / ICTP, Trieste**
Turbulence, planform of convection, boundary layer and plumes at high Rayleigh number
- 10:00 - 10:30** (Room: Adriatico Guest House (Terrace))
--- Coffee Break ---
- 10:30 - 12:30** **J. Niemala / ICTP, Trieste**
Turbulence, planform of convection, boundary layer and plumes at high Rayleigh number
- 12:30 - 14:00** (Room: Adriatico Guest House Cafeteria)
--- Lunch Break ---
- 14:00 - 16:00** **M. Manga / Univ. of California, Berkeley, USA**
Mixing and Volcanos
- 16:00 - 16:30** (Room: Adriatico Guest House (Terrace))
--- Coffee Break ---
- 16:30 - 18:30** **Visit to Laboratory**

Thermal convection: basics (Room:Adriatico Guest House Kastler Lecture Hall)

30 May 2011

- 09:00 - 10:30** **C. Jaupart / Inst. de Physique du Globe de Paris, France**
Introduction of energy equation. Boussinesq approximation.
- 10:30 - 11:00** (Room: Adriatico Guest House (Terrace))
--- Coffee Break ---

- 11:00 - 12:30** C. Jaupart / *Inst. de Physique du Globe de Paris, France*
Plumes and thermals. Use these to derive scaling relations for velocity as a function of power input and to discuss dynamical regimes (laminar vs. turbulent). Use plumes to illustrate Prandtl number, diffusion of heat and momentum and boundary layer structure. (Application of simple convection code)
- 12:30 - 14:00** (Room: Adriatico Guest House (Terrace))
 --- Lunch Break ---
- 14:00 - 15:30** C. Jaupart / *Inst. de Physique du Globe de Paris, France*
Rayleigh-Bénard convection (no internal heating). Heuristic argument to introduce Rayleigh number. Dimensional analysis. Rayleigh number, Prandtl number, Reynolds number for convective flow.
- 15:30 - 16:00** (Room: Adriatico Guest House (Terrace))
 --- Coffee Break ---
- 16:00 - 17:30** C. Jaupart / *Inst. de Physique du Globe de Paris, France*
Examples of convective systems: mantle, magma reservoirs. Marginal stability: Influence of boundary conditions (Free boundaries, rigid boundaries, fixed temperature, fixed heat flux).

Magmatic systems and thermal convection in the finite amplitude regime (Room:Adriatico Guest House Kastler Lecture Hall)

31 May 2011

- 09:00 - 10:00** R. Katz / *Univ. of Oxford, UK*
MAGMATIC SYSTEMS: MECHANICS. Derivation of conservation of mass & momentum equations. Scaling and the compaction length. Magma wave solutions.
- 10:00 - 10:30** (Room: Adriatico Guest House (Terrace))
 --- Coffee Break ---
- 10:30 - 12:00** R. Katz / *Univ. of Oxford, UK*
Latent heat of crystallization and melting. Stefan number. Diffusive cooling: pure substance. Mushy layers: observations (lava lakes). Mushy layers: models.
- 12:00 - 12:30** R. Katz / *Univ. of Oxford, UK*
Convection and crystallization in magma reservoirs: thermal and compositional.
- 12:30 - 14:00** (Room: Adriatico Guest House (Terrace))
 --- Lunch Break ---
- 14:00 - 15:30** C. Jaupart / *Inst. de Physique du Globe de Paris, France*
Equation for the horizontally averaged temperature and the convective heat flux Thermal structure of fluid layer: boundary layers and well-mixed interior.
- 15:30 - 16:00** (Room: Adriatico Guest House (Terrace))
 --- Coffee Break ---
- 16:00 - 17:00** C. Jaupart / *Inst. de Physique du Globe de Paris, France*
Free boundaries versus rigid boundaries. Large Prandtl number fluids. Convective loop model. Scaling relations for velocity and heat flux (no internal heating).
- 17:00 - 17:30** C. Jaupart, S. Zhong / *Inst. de Physique du Globe de Paris, France, Univ. of Colorado at Boulder, USA*
Convection driven by density anomalies in the Earth s mantle. Dynamic topography.

Complex rheology (magmas and temperature-dependent rheology) (Room:Adriatico Guest House Kastler Lecture Hall)

1 June 2011

- 09:00 - 10:00** **R. Katz / Univ. of Oxford, UK**
Thermodynamics & chemistry.
- 10:00 - 10:30** (Room: Adriatico Guest House (Terrace))
--- Coffee Break ---
- 10:30 - 12:00** **R. Katz / Univ. of Oxford, UK**
Equilibrium & disequilibrium formulations. Melting column solutions.
- 12:00 - 12:30** **R. Katz / Univ. of Oxford, UK**
Instabilities & the tectonic context. Mechanical and reactive melting instabilities. Magma-genesis and focussing at mid-ocean ridges
- 12:30 - 14:00** (Room: Adriatico Guest House Cafeteria)
--- Lunch Break ---
- 14:00 - 15:00** **C. Jaupart / Inst. de Physique du Globe de Paris, France**
Scaling for internally heated fluids. Thermal structure of fluid layer
- 15:00 - 15:30** (Room: Adriatico Guest House (Terrace))
--- Coffee Break ---
- 15:30 - 16:30** **S. Zhong / Univ. of Colorado at Boulder, USA**
Dissipation equation. New derivation of Nusselt number vs. Rayleigh number relationship
- 16:30 - 17:00** **S. Zhong / Univ. of Colorado at Boulder, USA**
Characteristics of plumes in Rayleigh-Bénard convection at high Ra

Complex rheology (Room:Adriatico Guest House Kastler Lecture Hall)

2 June 2011

- 09:00 - 10:00** **C. Jaupart / Inst. de Physique du Globe de Paris, France**
Temperature-dependent viscosity. Scaling for velocity and heat flux.
- 10:00 - 10:30** (Room: Adriatico Guest House (Terrace))
--- Coffee Break ---
- 10:30 - 12:00** **C. Jaupart / Inst. de Physique du Globe de Paris, France**
Non-Newtonian rheology. Non-Newtonian with temperature-dependent rheology. Scaling for velocity, heat flux, stress and strain-rate.
- 12:00 - 12:30** **S. Zhong / Univ. of Colorado at Boulder, USA**
Small-scale convection beneath oceanic and continental lithosphere
- 12:30 - 14:00** (Room: Adriatico Guest House (Terrace))
--- Lunch Break ---
- 14:00 - 15:30** (Room: Adriatico Guest House Informatics Lab.)
C. Jaupart, S. Zhong / Inst. de Physique du Globe de Paris, France, Univ. of Colorado at Boulder, USA
Practicals and exercises: problem sets + a few computer runs.

15:30 - 16:00 (Room: Adriatico Guest House (Terrace))
--- Coffee Break ---

16:00 - 17:30 (Room: Adriatico Guest House Informatics Lab.)
C. Jaupart, S. Zhong / *Inst. de Physique du Globe de Paris, France, Univ. of Colorado at Boulder, USA*
Practicals and exercises: problem sets + a few computer runs.

Miscellany of complicating factors (Room:Adriatico Guest House Kastler Lecture Hall)

3 June 2011

09:00 - 10:30 **C. Jaupart, P. Molnar / *Inst. de Physique du Globe de Paris, France, University of Colorado at Boulder, USA***
Chemical differences. Buoyancy number: Marginal stability, dependence on Rayleigh number and Buoyancy number.

10:30 - 11:00 (Room: Adriatico Guest House (Terrace))
--- Coffee Break ---

11:00 - 12:00 **C. Jaupart / *Inst. de Physique du Globe de Paris, France***
Two-layer mantle: convection regimes, thermal structure.

12:00 - 12:30 **C. Jaupart / *Inst. de Physique du Globe de Paris, France***
Evolution of initially stratified fluid

12:30 - 14:00 (Room: Adriatico Guest House Cafeteria)
--- Lunch Break ---

14:00 - 15:00 **S. Zhong / *Univ. of Colorado at Boulder, USA***
DEEP CONVECTION: Pressure-dependence of density: non-Boussinesq flow. Dissipation number, temperature scale height Isentropes and adiabats. Energy balance and scaling of dissipation with Rayleigh number.

15:00 - 15:30 **S. Zhong / *Univ. of Colorado at Boulder, USA***
Flow-induced anisotropy

15:30 - 16:00 (Room: Adriatico Guest House (Terrace))
--- Coffee Break ---

16:00 - 16:30 **S. Zhong / *Univ. of Colorado at Boulder, USA***
Secular cooling of the Earth: observations, theory, Urey ratio

16:30 - 17:30 **Final Remarks and Conclusion**