PAOLA VANNUCCHI

Earthquake Geology *(detailed program)*

Tentative Content plan – Still work-in-progress

Brittle failure, effective stress laws, friction, constitutive laws, continuum mechanics, and elasticity of faulting. Rate and state friction laws. State of stress in Earth's crust. Fault nucleation and growth. Fault rocks and structures. The strength and rheology of faults. Seismotectonics. Introduction to earthquake rupture. Instability conditions, energy balance, the work of faulting. Quantification of earthquakes. Earthquake source parameters and scaling laws. The seismic cycle, earthquake prediction

3 April	Monday	10.00-12.00	01 – Introduction: what is an Earthquake? Basic concepts - Mechanics of Earthquakes 02 – Stress tensor and the Mohr Diagram - Elastic deformation – Mohr-Coulomb failure Criterion –
3 April	Monday	14.00 16.00	03 –Experimental Techniques - Griffith Failure Criterion – Terzaghi's Principle and Pore Pressure 04 –
3 April	Monday	16.30 18.30	Discuss Handin, 1969 Handin 1969. On the Coulomb-Mohr Failure Criterion, Journal of Geophysical Research, 74-22, 5343-5348
Syllabus: The Mechanics of Earthquakes and Faulting, C. H. Scholz, 2002.	Ch. 1		**Brittle Fracture.** Milestones in continuum mechanics, concepts of modulus and stiffness. Stress-strain relations, elasticity, surface and body forces, tensors, Mohr circles. Theoretical strength of materials, Defects, Stress concentrations, Griffith failure criteria, fracture mechanics. Fracture toughness, Surface energy and Fracture energy. Cohesive zone, strain energy and the work of faulting. Macroscopic failure laws. Coulomb-Mohr criteria and stress-states. The strength of rocks. Experimental data. Pore fluid effects. Effective stress laws. Dilatancy hardening. The role of stiffness. Strain rate dependence of rock strength. Brittle vs. Ductile deformation, Dilatancy, Schizosphere, Plastosphere

4 April	Tuesday	10.00-12.00	05 – Friction: Theory and key concepts – Friction Experiments 06 – Friction: constitutive laws (Dieterich-Ruina)
4 April	Tuesday	14.00 16.00	07 – Constitutive laws application to EQ nucleation 08 – Fault rocks: classification and distribution. Pulverized rocks
4 April	Tuesday	16.30 18.30	Discussion: Rabinowicz, E., 1956. Stick and slip – Scientific American Di Toro, G; Goldsby, DL; Tullis, TE - Friction falls towards zero in quartz rock as slip velocity approaches seismic rates, NATURE Volume: 427 Issue: 6973 Pages: 436-439 Published: JAN 29 2004
Syllabus: The Mechanics of Earthquakes and Faulting, C. H. Scholz, 2002.	Ch. 2		**Rock Friction:** Amonton's laws. Concepts of static and kinetic friction. Bowden and Tabor's theory of friction. Asperities, adhesion, abrasion, wear. Stick-slip and stability of frictional sliding. Time dependent and memory effects. Fault re-strengthening and healing. Slip rate dependence of kinetic friction. Critical slip distance of friction, Rabinowicz's experiments. Rate and state friction constitutive laws. Elastic coupling and solution of history-dependent equations. Forward models of velocity-step tests and frictional healing. Processes and mechanisms of friction, complex behavior, strain rate dependence, slip history effects, normal stress effects. Forward models and constitutive laws for friction

5 April	Wed	10.00 - 12.00	09 – Anderson Theory –Andersonian and non-Andersonian faults 10 – Methods to determine Stress orientation - Stress Field orientation in the crust – Is the crust at critical failure?
5 April	Wed	14.00 16.00	11 – Fault zone structure 12 – Pseudotachylytes: Fossil Earthquakes. Fault lubrification during seismic rupture; Fault geometry and Earthquakes
5 April	Wed	16.30	Discussion:

		18.30	Bakun et al., 2005. Implications for prediction and hazard assessment from the 2004 Parkfield Earthquake – Parkfield, Nature, 437, 969-974. Chiarabba C., Jovane L., Di Stefano R., 2004, A new view of Italian seismicity using 20 years of instrumental recordings. Tectonophysics, 395, 251-268. Montone; Mariucci; Pierdominici, 2012 The Italian present-day stress map. Geophysical Journal International 189 2 705-716 Montone, P; Mariucci, MT; Pondrelli, S; et al. 2004 An improved stress map for Italy and surrounding regions (central Mediterranean). Journal Of Geophysical Research-Solid Earth, 109 B10 Article Number: B10410 Townend, Zoback, 2000. How faulting keeps the crust strong, Geology, 28, 399-402.
Syllabus: The Mechanics of Earthquakes and Faulting, C. H. Scholz, 2002.	Ch. 3		**Fault Mechanics.** Andersonian Faulting. Hubbert-Rubey theory. State of stress in the crust. Shear heating. Fault growth. **Fault Rocks and Fault Strength.** Faulting in nature. Fault rocks and fault zone thickness. Wear in natural fault zones. Fault zone rheology. Depth variation of fault rocks and structures. Fault zone fabrics. Fault zone heterogeneity.

6 April	Thu	10.00 - 12.00	13 – Episodic tremor and slip 14 – Earthquake quantification (M_L, M_s, M_w, M_o) and energy partitioning of earthquakes
6 April	Thu	14.00 16.00	15 – The Seismic cycle 16 –
6 April	Thu	16.30 18.30	Discussion: Di Toro, G.; Han, R.; Hirose, T.; et al. 2011 Fault lubrication during earthquakes, NATURE 471 494- Rogers, G; Dragert, H, 2003 Episodic tremor and slip on the Cascadia subduction zone: The chatter of silent slip SCIENCE: 300, 5627 1942-1943 Shelly, DR; Beroza, GC; Ide, S; et al 2006 Low-frequency earthquakes in Shikoku, Japan, and their relationship to episodic tremor and slip NATURE 442 7099 188-191
Syllabus: The Mechanics of Earthquakes and Faulting, C. H. Scholz, 2002.	Ch. 4, 5		**Earthquake Mechanics.** Magnitude, seismic moment, quantification of earthquakes. Focal mechanisms, Source parameters. Particle velocity, rupture velocity. Seismic stress drop: static and dynamic. Seismic efficiency. Seismic spectra and interpretation. Rise time, rupture duration. **Earthquake rupture nucleation.** Friction and fracture mechanics approach to nucleation. The critical slip distance for seismic faulting. Critical rupture patch size. The transition from quasistatic to dynamic rupture. Laboratory data. Seismic data**. The seismic cycle.** Repeating earthquakes. Rupture characteristics, time dependence. Relation to laboratory-derived constitutive laws.

7 April	Friday	10.00- 12.00	17 – Seismotectonics 18 – Earthquake Prediction and hazard analysis
7 April	Friday	14.00 16.00	Discussion: Doglioni, Carminati, Petricca, Riguzzi, 2015. Normal Fault Earthquakes or graviquakes. Scientific Reports, 5. Boschi, E. 2016 La Leggerezza e la Superficialita'. Una storia non finita. Il foglietto della Ricerca, 10 Novembre Boschi, E. 2016. La sismologia e' una scienza galileiana. Il foglietto della Ricerca, 3 Novembre Boschi E. 2017. Il president della commissione grandi rischi e l'effetto Vajont. Il foglietto della ricerca. 2 Febbraio
7 April	Friday	16.30 18.30	Aperitivo
Syllabus: The Mechanics of Earthquakes and Faulting,	Ch. 5, 6, 7		**Earthquake scaling laws.** f_{max}, f_c. Frequency dependence of seismic moment. Strong motion data. $f^{-\omega}$ models and interpretation. **Seismotectonics.** Fault rheology from seismic studies. Depth-frequency relations for seismicity. Strong motion studies. Earthquake afterslip and the relation between coseismic and

C. H. Scholz, 2002.		postseismic slip. Fault heterogeneity, slip heterogeneity. **Earthquake Prediction.** Earthquake triggering and fault interaction. Precursory phenomena. Historical observations.

Siti web consigliati:

- U.S. Geological Survey: http://earthquakes.usgs.gov/
  http://earthquake.usgs.gov/eqcenter/eqarchives/poster/
- SAFOD (San Andreas Fault Observatory at Depth):
  http://quake.wr.usgs.gov/research/parkfield/safod_pbo.html
  http://www.icdp-online.org/contenido/icdp/front_content.php?idcat=896
- California Geological Service: http://www.consrv.ca.gov/CGS/geologic_hazards/earthquakes/index.htm
- INGV www.ingv.it

Testo di riferimento

- Scholz, C.H., 2002. *The mechanics of earthquakes and faulting*. Cambridge Press, New York.

Testi consigliati

- Abercrombie, R., McGarr, A., Kanamori, H., Di Toro, G., 2006. Earthquakes: Radiated Energy and the Physics of Faulting. Geophysical Monograph 170, American Geophysical Union, Washington DC (USA).
- Price N.J., Cosgrove, J.W., 1990. Analysis of Geological Structures, Cambridge University Press.
- Rabinowicz, E., 1965. Friction and Wear of Materials. John Wiley, New York.
- Snoke, A.W., Tullis, J., Todd, V., 1988. Fault related-rocks: A photographic atlas. Princeton University Press.
- Twiss, R.J., Moore, E.M., 1992. Structural Geology, Freeman, San Francisco.