

Planetary Collisions, UCSC Earth and Planetary Sciences, Fall 2010

Instructor: Erik Asphaug, asphaug@ucsc.edu, E&MS A108**Textbook:** Melosh (1989) "Impact Cratering: A Geologic Process"**Meetings:** Monday 2:30-5:30 E&MS D250 (2:30-4:00 lecture; 4:15-5:30 discussion)

Introduction. This course is a lecture and readings-based seminar that spans planetary dynamics and formation; cosmic bodies such as satellites, comets and asteroids; the physics of impact cratering and planetary collisions; the impact record that probes beneath planetary surfaces and serves as a unique chronometer; and something about meteorites.

Planetary collisions are distinguished from impacts in being larger in spatial scale and longer in time scale, and non-localized. This makes their physics interesting and non-intuitive, analogous in many respects to landslides, massive-amplitude tides, earthquakes, volcanic eruptions, and fluid deformation (think lava lamps). Impacts are local and their physics can be well-approximated as explosive detonations where specific internal energy $u=v^2/2$ is assigned to a projectile-mass of target material buried a few projectile-radii deep. Impact physics can be further simplified in the context of a half-space target, to yield useful scaling relations which are accurate under many circumstances. The complexity of impact cratering has mostly to do with the complex behavior of target geologic rocks (or oceans, or atmospheres) in response to high strain-rate and thermally altering events.

Many new inroads are being made in the field of impact cratering, thanks to improvements in computer codes, and to the availability of much improved rheological descriptions and EOS packages. There is also a growing connection between impact crater geology and impact modeling, with several researchers doing excellent work in the field and the computer lab. We shall study 3-5 papers on modern developments. Despite these new developments, there have not been any profound major changes in impact cratering since Melosh wrote his classic, comprehensive textbook which we shall read as the foundation of our studies.

Much has been learned about planetary collisions since the textbook was written, where in addition to impact physics we need to understand the complex interactions involving integrated fluid behaviors of the projectile and the target; characteristically a body the size of Vesta plows through the mantle of a Moon-sized body and emerges on the other side; this is not cratering though it is closely related. The possibilities for meteoritics are endless. Self-gravity is central to the process: during oligarchic and late-stage planetary formation (and perhaps during all of terrestrial planet formation) the largest collisions take place at projectile-target velocities comparable to their mutual escape velocity $v_{esc}=\sqrt{2G(M+m)/(R+r)}$, and this aspect of the dynamics contributes to unique characteristics which have a dynamical similarity to certain kinds of stellar and galactic collisions, where objects are shredded by tides, shocks and shears.

A second departure in the study of impacts on small bodies (planetesimals, moons, asteroids and comets), where when the textbook was written we had never seen a picture of an asteroid. We will spend time studying impacts and collisions in

the context of a rapidly-collisionally-evolving accreting planetary system, where for this place in this solar system, an Earth-amount of mass accreted, in bursts, at an average rate of a million tons per second ($\sim M_{\text{Earth}}/100 \text{ Ma}$). Accretion is one big long-term collision.

Here is how the course works:

Final Project: a term paper of 10-20 pages (or equivalent – can be a data analysis or a series of simulations). Your project might include counting craters to answer a puzzle about a planetary surface age or evolution, or developing a quantitative model of regolith evolution, impact degradation or block/meteoroid distribution; or running and analyzing code models of impacts and post-impact evolution. It can be a scholarly review of an important planetary debate in the literature (Moon formation; primary accretion; geology of Chicxulub; Libyan desert glasses; impacts into Jupiter; the Younger Dryas 'impact event'). It can be a proposal for research funding to NASA. It can be something you're working on for your thesis. You will present your project idea to the class informally, during the discussion period after we've finished the midterm (no presentation materials required, just what's left of your brain). Your final project is due in written form on **Nov. 29**; you may elect to email it (or parts) to the class in anticipation of a 30 minute presentation you will each give to the class during the last class day.

Grading: The final project (the sum of the parts above) is 50% of your grade. An open-book midterm exam is 25% of your grade. Class participation is 25% of your grade. Participation does not mean talking; it includes listening thoughtfully, bringing coffee for everyone, or reminding us that it's time to take a break already.

It is a bad idea not to not keep up with the readings.

Attendance: If you know you are going to be absent, make sure to send me an email the Friday before. More than one absence will be problematic for a once-a-week graduate course. Please alert me to any special events that we shall need to accommodate. Based on past experience we will need one or two make-up classes; if possible please keep **Wed 2:30-4:00** and **Fri 2:30-4:00** available, TBD.

Field trip: I am working to coordinate a field trip to monitor explosions at the Aromas mine (about 30 minute drive from here), either during class or on a W or F afternoon. This will be at rather short notice (they blast according to their own schedule) so attendance will not be required. Also remember that their hope is that their explosions result in a slump failure and are relatively boring – somebody find a wealthy donor who will fly us all out to the Nevada Test Site!

Extra-curricular. As fortune would have it, two Astronomy colloquium speakers this week will lecture about planetary collisions. One of them is me, Wed Sep 29 4:00-5:30, and the other is Robert Marcus, Fri Oct 1 12:30-1:30. In addition there is Planetary Lunch on Tuesdays 12:30-1:30, and the WES and CODEP seminars on Tuesday and Friday afternoons, which sometimes feature planetary violence. We will be lucky enough to have some guest speakers give overviews and answer questions in topics such as crater geomorphic evolution, large impact structures, and atmospheric interactions.

Syllabus. Readings are listed here together with a lecture/discussion overview. I want you to *really learn* the textbook material (hence the open-book midterm) so you should read the assigned textbook chapters once before class, just making a note if you don't get something, and then a second time following class. The first half of class is usually a lecture, and the second half of class is generally discussion.

Week 1 – Monday 9/27/2010

Preface; Chapter 1; Chapter 2

Introduction to class; format; textbook
The history of the science of impact cratering
Snapshot of modern accretion theory
Latest thoughts in meteoritics/timing/ages
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Images of impact craters and collisional relics
Quick overview: impact coupling; shocks;
excavation stage, momentum coupling, rubble
flow, strength and gravity (and what *is*
strength?), catastrophic disruption

Week 2 – Monday 10/4

**Chapter 3: Stress waves in solids
Appendix I: Hugoniot Relations**

Stress waves in solids
Ideas about strength
Granular solids and constitutive models
<break>
Shock waves and EOS models

Week 3 – Monday 10/11

**Chapter 4: Contact and Compression
Appendix II: Equations of State
Artemieva and Lunine 2003, Asphaug 2010**

Contact, compression and release
Fate of the projectile
Hit-and-run collisions
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Petrological implications
Discussion

Week 4 – Monday 10/18

Chapter 5: Excavation of impact craters

Momentum deposition behind the shock
Rock disruption behind the shock
Kinds of fluid motion behind the shock –
Vapor and melt; rubble
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Maxwell Z-model
Acoustic fluidization
Guest speaker Martin Jutzi

Week 5 – Monday 10/25

Chapter 6: Ejecta deposits

Midterm Exam

Instant gratification: midterm solutions

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Present your project idea

Week 6 – Monday 11/1

**Chapter 7: Scaling of crater dimensions
Housen and Holsapple 2001**

Scaling of crater dimensions: power laws
Catastrophic disruption scaling (Q^*)
Fracture and fragmentation
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Mathilde and other weird objects
Critical crater diameter on asteroids

Week 7 – Monday 11/8

Chapter 8: Modification stage

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Guest speaker Misha Kreslavsky TBC

Week 8 – Monday 11/15

**Chapter 9, 10: Multiring basins; cratered
landscapes**

Physics of multiring basins
McKinnon and Melosh models
Europa; Zunil
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Dawn mission to Vesta – what will they find?

Week 9 – Monday 11/22

**Chapter 11: Atmospheric interactions
Boslough et al (2004)**

Shoemaker Levy 9
Tunguska
Mars rampart craters (Schultz model)
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Guest speaker TBC

Week 10 – Monday 11/29 – Final Projects Due

**Chapter 12: Planetary evolution
Canup (2004); Benz et al. (2008)**

Formation of the Moon
Formation of Phobos and Deimos by impact?
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Computer modeling

Final Exam Period -- TBD

Final project presentations