76^{th} Arthur H. Compton Lecture Series

Constructing the Solar System: A Smashing Success!

Lecture 6: Making Things Hot — The thermal effects of collisions

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1 Introduction

Last week we saw some of the collateral effects of collisions between planetesimals. We found that collisions between porous planetesimals can cause much more heating than those between non-porous bodies. In this week's lecture, we will study the thermal evolution of a meteorite parent body, and compare the role of the decay of short-lived radionuclides and collisions in the heating process.

2 Evidence of heating

We know that planetesimals were heated early in their lifetimes (within the first 5–10 million years). Evidence for this includes:

- **Metamorphism**: In chondritic meteorites, the level of metamorphism can provide clues to the temperature that the material reached after formation.
- **Differentiation and melting**: In achondrite and iron meteorites, we have evidence that the parent body melted and differentiated (i.e. the metallic elements sunk to the core, leaving a silicate mantle with a distinct chemistry).

Using radiometric dating and measurements of isotopic signatures, we can determine the peak temperatures, cooling rates and the timing of the heating events.

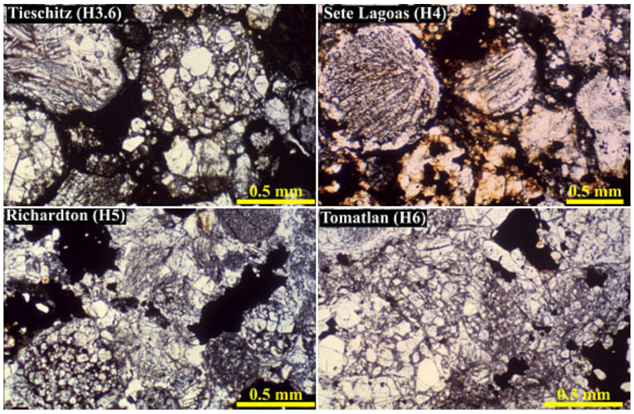

Figure 1: Textures in H chondrites of different metamorphic types. In type 3 (low metamorphism) meteorites, the chondrule edges are sharp. In types 4 and 5, the edges become less well defined, and in type 6, the boundaires between the chondrules and the matrix are poorly defined. These textures are indicators of metamorphism (i.e. heating) on the planetesimal after formation. Image courtesy of Gary Huss.

3 Heat sources

The two main sources that are expected to have provided the heat for metamorphism and melting are the decay of short-lived radionuclides and impacts.

3.1 Short-lived radionuclide decay

Unlike on planets, where long-lived radionuclides such as uranium, potassium and thorium can provide vast amounts of heat, on small bodies those heat sources would be too inefficient to cause the early heat signatures that we see in meteorites. Therefore, shorter-lived radionuclides are necessary to explain the heating. Two such radionuclides, that are thought to have been abundant in the early Solar System, are ^{26}Al and ^{60}Fe, which decay with half lives of 0.7 million years and 2.6 million years, respectively. The decay of these radionuclides is expected to have led to what is known as an *onion shell* structure, in which the hottest material is situated in the center of the body, and progressively cooler layers are found towards the surface. In this model, the hottest material would have cooled the slowest (as it was in the center, where it would have been thermally insulated).

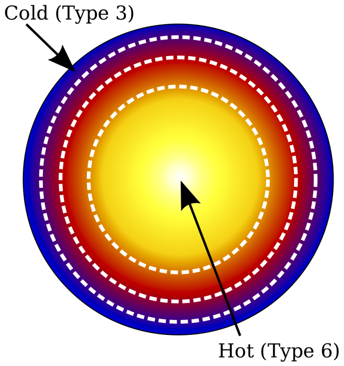

Figure 2: The onion shell structure of a planetesimal, caused by heating from radionuclide decay. The hottest material would be situated in the center of the planetesimal, with the outer layer becoming progressively colder.

Models of this heat source for the H chondrite parent body were able to explain most of the measurements of cooling rates and closure times (the time the material cooled through a given temperature). However, some observations cannot be explained by this heat source alone: in some cases, the trend for the hottest material to cool the slowest is not observed. It is proposed that impacts could provide the source for these anomalies.

3.2 Collisions

If planetesimals were porous in the early Solar System, impacts could have a dramatic effect on their thermal history. We saw last week that the shock physics of collisions between porous objects could lead to much more heating than an equivalent collision between non-porous objects. Since our model of planetesimal formation predicts the creation of porous planetesimals, impacts could be significant heating events.

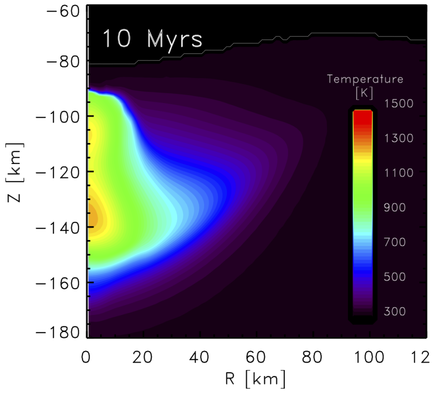

Figure 3: The thermal signature beneath an impact crater, 10 million years after the collision. The peak temperauture is still >1100K.

We have run some computer simulations, in which the projectile is strongly heated and subsequently buried beneath an insulating breccia lens. The thermal signature from such an event could remain in a porous planetesimal for 10s to 100s of millions of years. The material heated by impacts could explain how some cooling rate measurements do not fit the onion shell model. The cooling rates and closure times from one impact simulation can provide as good a match to the measurements from the H chondrite parent body as the onion shell models. As every parent body is expected to have undergone many hundreds of collision events, the role of impacts on the thermal evolution of asteroids is very important.

4 Next lecture

Next week we will look at the impact history of our Moon, starting with the collision that is expected to have formed the Moon, and then looking at what impacts on the Moon's surface can tell us about the history of the Solar System.