THERMAL MODELS OF ASTEROIDS. J.W. Minear, NASA-Johnson Space Center, Houston, TX 77058, G. Clow, Lunar and Planetary Institute, Houston, TX 77058, and C.R. Fletcher, Lockheed Electronics Co., Inc., Houston, TX 77058.

Prevailing wisdom, derived primarily from meteorite studies and spectral observations of main-belt asteroids, is that asteroids are the parent bodies of the vast majority of meteorites. Meteorite data have been used to develop interior models of asteroids (1,2) and to limit the size of asteroid parent bodies (3-7). These models imply melting and differentiation of the asteroids and the production of basaltic melts is required by achondritic meteorites. Recent observations of visible and near infrared reflectance spectra from asteroids have strengthened the link between meteorites and asteroids and the case for melting and differentiation of asteroids with attendant production of basaltic melts. We present some results based on thermal model calculations that include early heating, melting, core formation, fractionation of radioactive elements, crystal settling, and convective heat transport.

Old formation and crystallization ages found for meteorites and attributed to their asteroid parent bodies and the small size of asteroids have led to the general consensus that an early, intense, and short-lived heating agent is needed to produce melting in asteroids. We have chosen ^{26}Al because evidence of its presence in meteorites has been reported (8) and its energy production is easily quantifiable. Concentrations at the time of accretion were 250 ppb ^{26}Al and chondritic for U, Th and K.

Intense, short-lived (half life less than about 10^7 yrs) heat sources produce nearly isothermal asteroids during early heating, except for a very thin ($\lesssim$ few kilometers) conduction boundary layer at the surface. If melting is to be produced before they decay to insignificance they must generate heat at a rate that overwhelms conductive heat loss. The result is that any melting will occur throughout the asteroid at the same time (except for the surface boundary layer). Melting throughout the entire asteroid except for a conduction boundary layer is also characteristic of transverse magnetic mode electrical induction heating (9).

As melting proceeds, an immiscible iron-rich liquid may sink and displace silicate melt. Efficient migration of ^{26}Al into the early silicate melt phase and subsequent displacement of this melt may prevent complete melting of the core region. This would result in a core region containing an inter-mixture of silicates and iron. If, however, the iron melt can also displace the silicate matrix upward, a silicate-free iron core may result. The core will be formed very early — within 10^6 yrs of accretion — and will cool almost isothermally because of its high thermal conductivity and the low-conductivity silicate blanket around it. Core cooling rates at 700°C are 0.64 and 22°C/m.y. for 500 and 100 km radius asteroids respectively. Cooling rates decrease by about a factor of two from 700°C to 300°C.

If ^{26}Al does not efficiently migrate to the surface then the silicate surrounding the core will melt completely in about 10^6 yrs and will remain liquid until the ^{26}Al heating has dissipated sufficiently to allow crystallization to begin. Time from accretion, through melting, to total solidification is 30×10^6 and 712×10^6 yrs for 100 and 500 km asteroids respectively. On the other hand, if melt carrying the bulk of the radioactivity is efficiently squeezed out of the interior of the silicate shell, the shell may be only partially melted. Post-solidification cooling in either case will be dominated by conductive heat loss. Cooling rates midway between the core and the surface at 700°C are about 18°C and 0.7°C for 100 and 500 km radius asteroids respectively. Cooling rates at 300°C at the same position are about a factor of two lower.

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Several lines of evidence suggest that the porosity of asteroids shortly after accretion should be significant. The porosity of carbonaceous chondrites is generally observed to be quite high; measured chondrite porosities average about 11% (10). Low collisional velocities necessary for accretion (11,12) should result in little compaction. The central pressures of even the largest asteroids are at most a few kilobars. Compaction experiments on powdered basalt (13) suggest that these pressures will reduce an initial porosity of even 25% by only about one-fourth. Given that asteroids accreted with porosities of about 10% under vacuum conditions, their thermal conductivity may be two orders of magnitude lower than solid rock.

Lower conductivity does not affect the models if an intense short-lived heat source is present. Even with solid rock thermal conductivities, heating overwhelms diffusive heat loss. In contrast, a lower thermal conductivity has a critical effect on thermal evolution when only long-lived heat sources are considered, i.e., U, Th, and K. Using a model that increases the thermal conductivity with temperature from about 6×10^3 ergs/cm·°C·sec at 200°K (accretion) to 3.7×10^5 ergs/cm·°C·sec at 1373°K (melting), it was found that chondritic concentrations of U, Th, and K (no ^{26}Al) can produce melting in the interiors of asteroids as small as 400 km in radius. Partial melting occurred after about 10^9 yrs and persisted for a few hundred million years in a 400 km asteroid.

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