ABSOLUTE CHRONOLOGY AND IMPLICATIONS FROM GEOPHYSICAL MODELING OF IAPETUS. D. L. Matson[1], J. C. Castillo-Rogez[1], C. Sotin[1,2], T. V. Johnson[1], J. I. Lunine[1,3], (1) Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109. (2) UMR – CNRS 6112 Laboratoire de Planétologie et Géodynamique de Nantes, 2, rue de la Houssinière, 44322 Nantes Cedex 3, France. (3) Lunar and Planetary Lab, 1629 E. University Blvd. Tucson, AZ 85721-0092.

Iapetus has preserved evidence that constrains the modeling of its geophysical history from the time of its accretion until now. This evidence is (a) its present 79.33-day rotation rate, (b) its shape that corresponds to the equilibrium figure for a hydrostatic body rotating with a period of ~16 h, and (c) its sharp, equatorial ridge, which is unique in the Solar System.

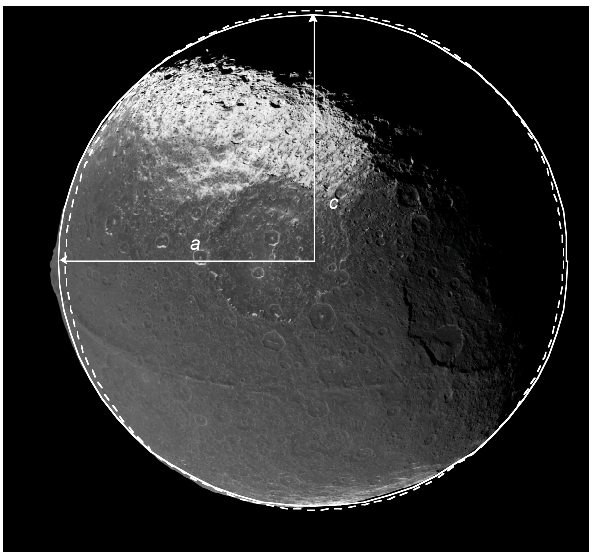

Fig. 1. Iapetus as seen by Cassini on December 31, 2004. The solid curve shows the shape of the satellite. The dashed curve indicates the shape the satellite would have if it were in hydrostatic equilibrium today. Given Iapetus' present rotation period and semi-major axis, a deviation from spherical of no more than 10 m is expected. The actual deviation is 33 km.

We have investigated the coupling between Iapetus' thermal and orbital evolution [1] for a wide range of conditions including the radial distributions with time of composition, porosity, short-lived radioactive isotopes (SLRI), and temperature. The thermal model uses conductive heat transfer with temperature-dependent conductivity. Only models with a thick lithosphere and an interior viscosity relatively close to the water ice melting point can explain both the observed shape and despinning to the current rotation period. Short-lived radioactive isotopes provide the heat that decreases porosity in Iapetus' early history. This increases thermal conductivity and allows the development of the strong lithosphere needed to preserve the 16-h rotational shape and the vertical relief of the topography. Long-lived radioisotopes and SLRI raise internal temperatures high enough that significant tidal dissipation can despin Iapetus to synchronous rotation. This occurred several hundred million years after Iapetus formed.

Such models also constrain the time when Iapetus formed because the successful models are critically dependent upon having just the right amount of heat added by SLRI decay in this early period. The amount of heat available from short-lived radioactivity is not a free parameter but is fixed by the time when Iapetus accreted, by the canonical concentration of ^{26}Al, and, to a lesser extent, by the concentration of ^{60}Fe. The needed amount of heat is available only if Iapetus accreted between 2.5 and 5.0 Myr after the formation of the calcium aluminum inclusions as found in meteorites. Models with these features allow us to explain Iapetus' present synchronous rotation, its fossil 16-h shape, and also provide a context for explaining why the equatorial ridge arose.

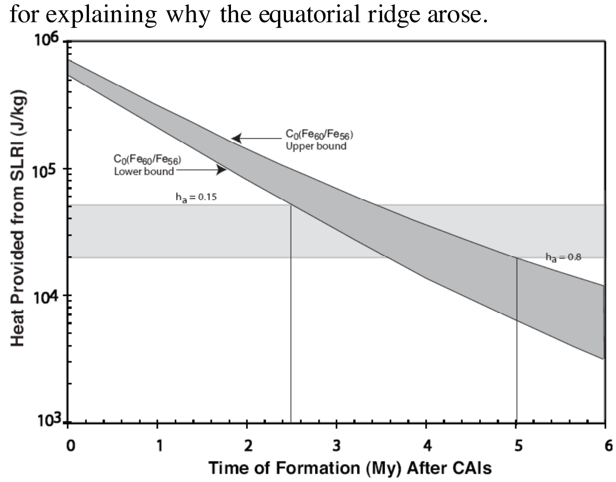

Fig. 2. The heat needed by Iapetus models (light grey band) compared with available heat after the formation of CAIs (curved band). Band widths show allowances made for the uncertainties in the Iapetus models and in the composition and initial isotopic ratios. The width of the available heat zone is chiefly due to the uncertainty in the initial abundance of ^{60}Fe. The light grey zone indicates the amount of heat needed for Iapetus to despin and yet preserve its non-hydrostatic shape until the present. The upper bound assumes little heat is provided by accretion and thus more is needed from SLRI. The lower bound assumes 80% of accretional energy is used to heat the satellite, and thus less heat is needed from SLRI. The intercept between the two zones yields the time of formation of Iapetus with respect to CAIs.

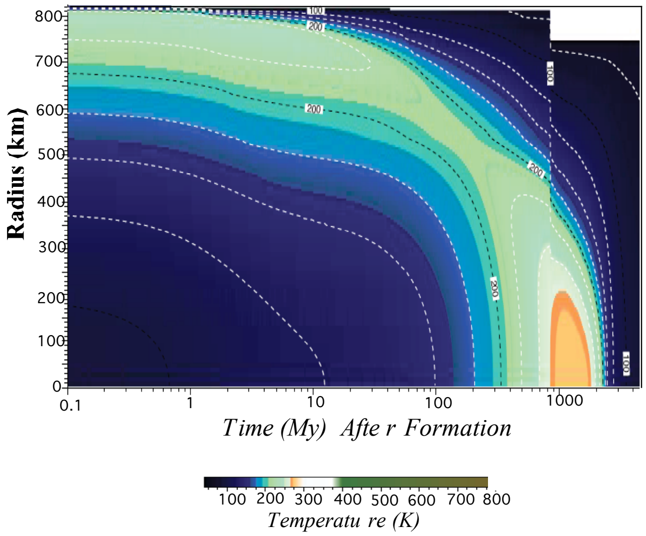

Fig 3. Thermal evolution model for Iapetus. Temperature is plotted as a function of equatorial radius and time (on a log scale) since accretion. The time at the extreme right is the present. Temperature is contoured every 25 K. The color scheme indicates geophysically significant temperatures. The time of formation with respect to CAIs is 5 My, The model assumes that 80% of accretional energy retained as heat. This model can successfully explain Iapetus' despinning to synchronous rotation. When despinning occurs, at about 700 My after formation, the spin period rapidly evolves while the lithosphere is thick enough to support large-scale non-hydrostatic topographic anomalies.

If we accept the Pb–Pb age of CAIs measured by [2] of 4567.2 ± 0.6 Myr, then the age of Iapetus is between 4562.2 and 4564.7 Myr.

Since Iapetus is almost certainly a regular satellite of Saturn, rather than a captured object [3], the absolute chronology obtained sets a limit of five million years to form Saturn. This is consistent with the independent evidence that the time scale for giant planet formation is millions, rather than tens of millions, of years. Recent astronomical observations suggest that the lifetime around Sun-like stars of sufficient gas to make giant planets may be typically two to five million years [4]. Models for the formation of giant planets by direct collapse can easily meet this time constraint [5]. The nucleated instability model of giant planet formation may be more relevant to the giant planets of our own Solar System, with their supersolar heavy element abundances and regular satellite systems, but only under certain restricted conditions do they seem able to produce gas giant planets within a few million years [6]. A somewhat weaker constraint on giant planet formation time scales comes from dynamical calculations that show the presence of Jupiter and Saturn to be important determinants of the final architecture of the terrestrial planet orbits and asses [7], coupled with the fact that much of the growth of the Earth was completed within 10–30 million years after CAIs based on the Hf–W isotopic system. Our time scale result provides an additional indication that giant planet formation was relatively rapid in our own Solar System and gives impetus to the further development and elaboration of the nucleated instability models for giant planet growth.

We will also report on the September 10, 2007 flyby that will provide observations of Iapetus obtained as close as 1600 km altitude

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