WIDMANSTÄTTEN PATTERN GROWTH IN IMPACTED, MANTLE-STRIPPED IRON METEORITE PARENT BODIES.

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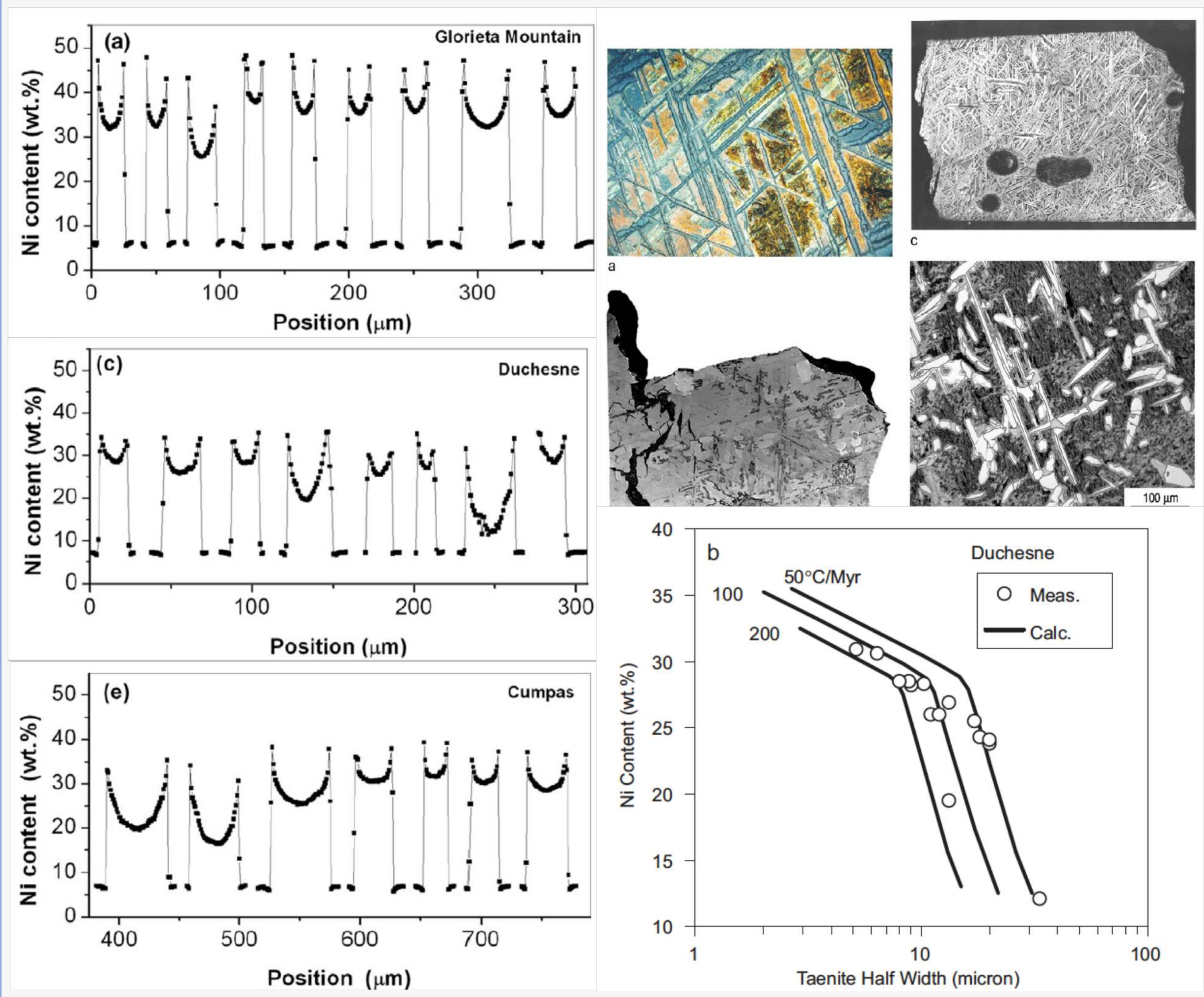
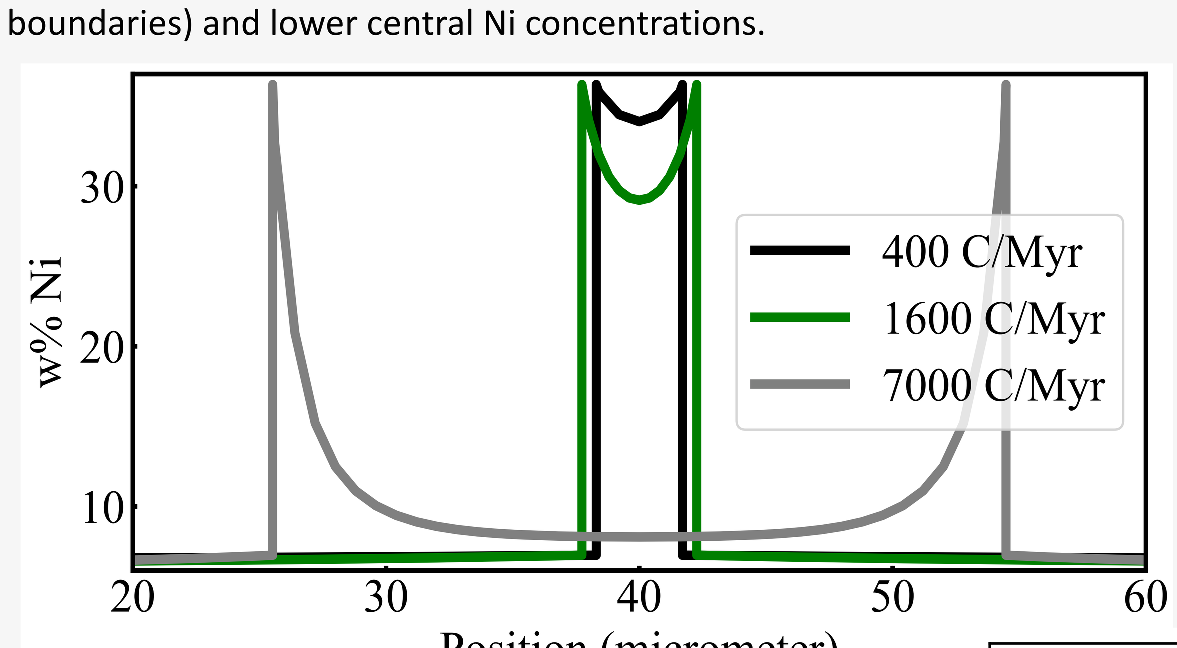
Introduction

The Widmanstätten pattern in iron meteorites is a direct reflection of the thermal evolution of their parent bodies. As grain growth and Ni diffusion are temperature dependent, the observed grain sizes and Ni-concentrations in meteoritic samples can be compared to predictions of numerical models to determine the cooling rates that the samples experienced [1-3]. To date, these numerical models have focused on constant cooling rates [4-6], however it is possible that cooling rates varied, at times significantly, as the patterns developed. This is particularly true in bodies that were subjected to high energy [7] or hit-and-run [2,4] impacts, which would accelerate the cooling of a given body. Here we investigate the effects of non-constant cooling rates on iron meteorites, and discuss the implications for identifying and constraining the collisional histories of their parent bodies.

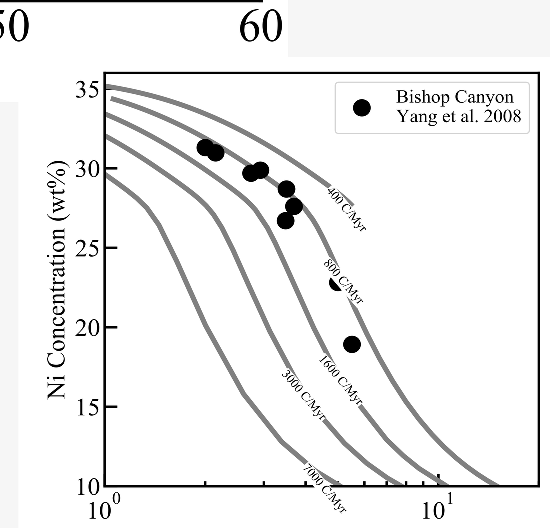


Widmanstätten Formation Model

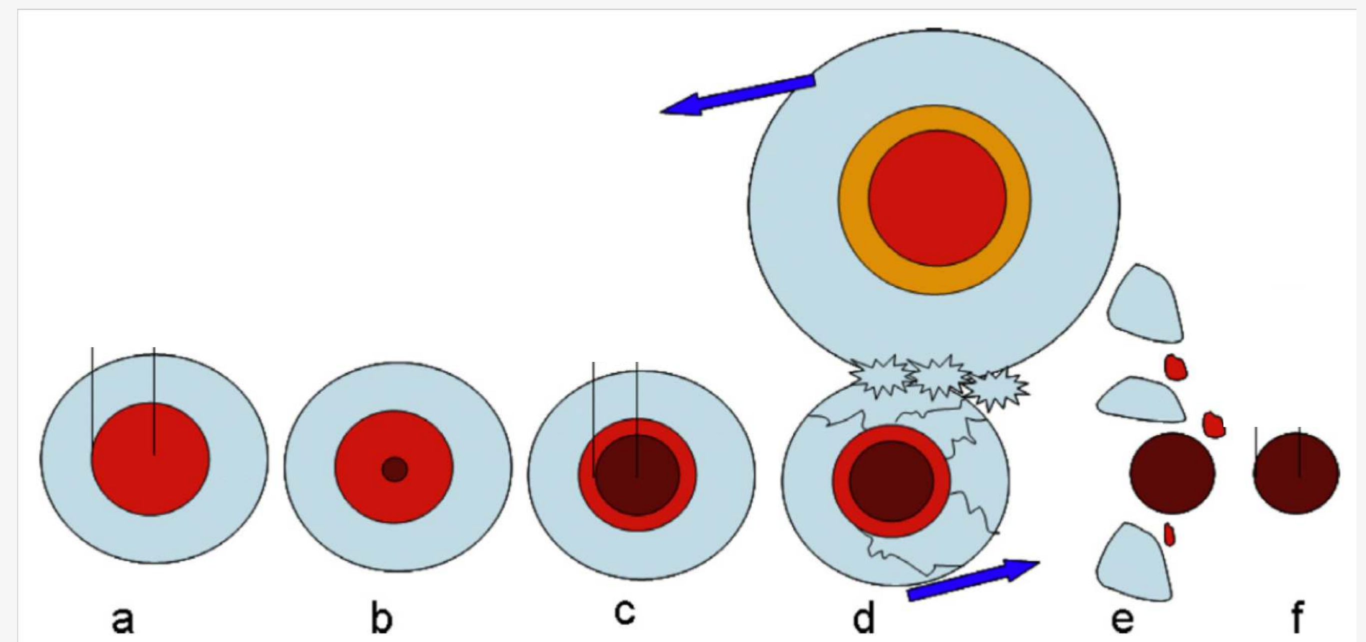
We have modified the 1D Ni diffusion model described in [6], which utilizes a front-tracking, fixed finite-difference grid methodology described by [8]. The phase diagram of kamacite and taenite used here is described in [5]. The left-hand side of the figure below illustrates the cooling rate dependence of the Ni-concentration profiles that develop in our model. Faster cooling rates yield larger taenite half-widths (distance between the kamacite-taenite boundaries) and lower central Ni concentrations.



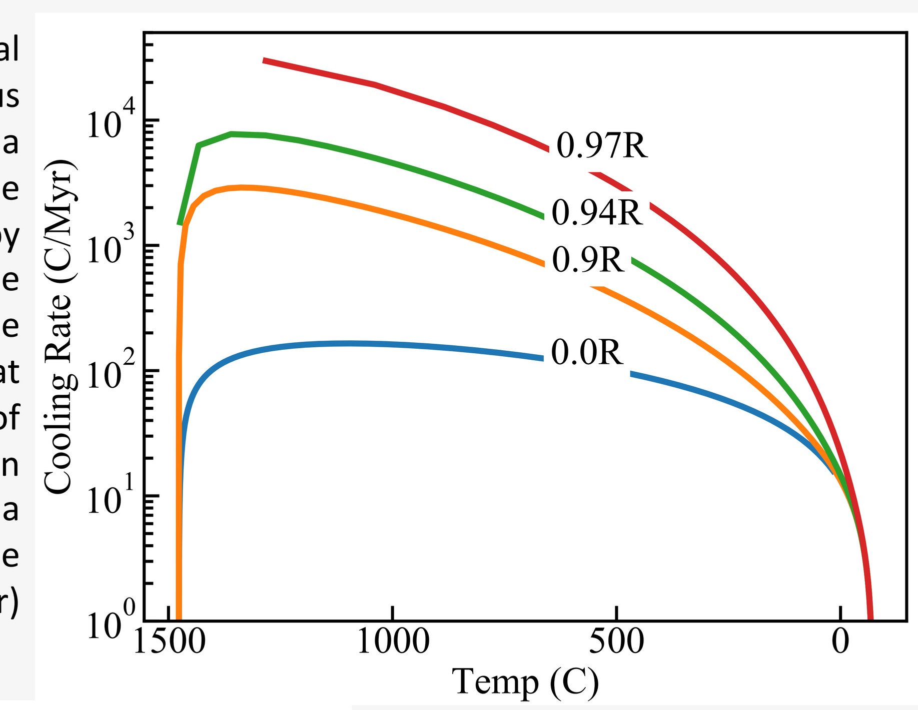
Varying the initial impingement length yields curves on a Wood diagram from which the cooling rate of a given iron meteorite can be estimated. The right-hand side of the figure above shows model results for various constant cooling rates, assuming meteorite compositions of the Gibeon. The black dots are measured values as reported in [4].

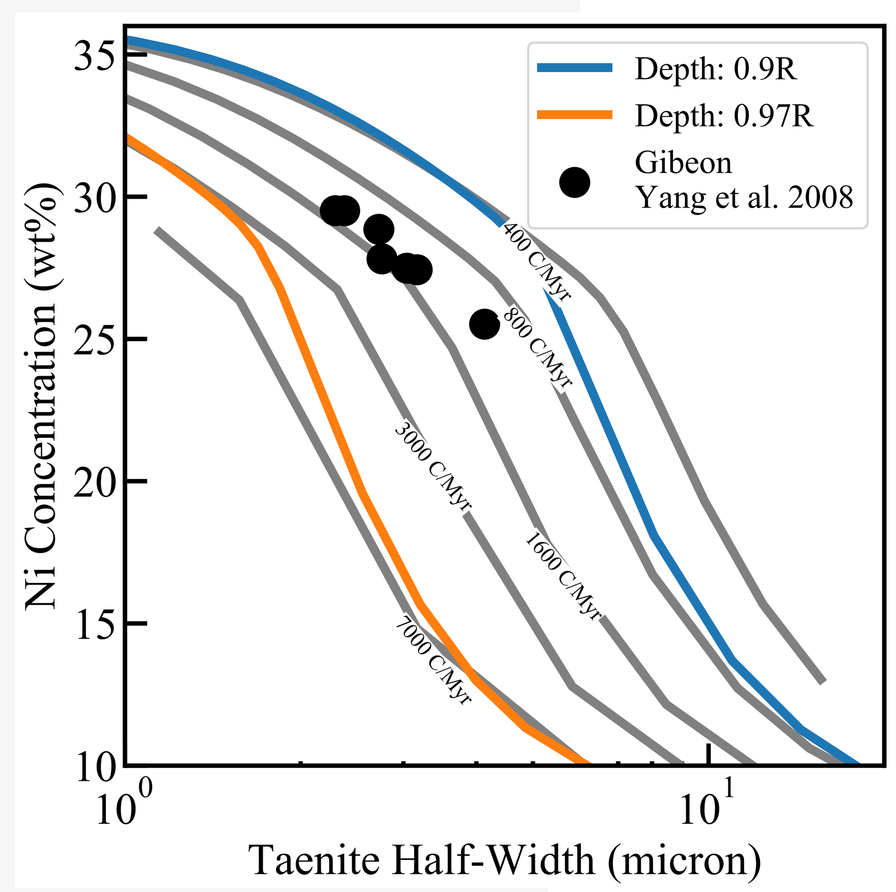


Mantle-Stripped Bodies



We tracked the thermal evolution of a 150 km radius mantle-stripped iron core using a 1D conductive code [9] with the same parameters as inferred by [2,4] for the IVA parent body. The figure to the right shows the cooling rates that materials at different depths as a function of temperature. The cooling rate in an iron body will not only be a function of depth (faster near the surface, slowest at the center) but also temperature.





We ran a suite of simulations using the above thermal profiles in order to predict where samples would fall on a Wood diagram using the same parameters as the Gibeon meteorite (to the left) and Bishop Canyon (below) meteorites. The mantle-stripped curves show the variations in cooling rate, matching the rapid cooling rates experienced early in the growth of the Widmanstätten Pattern when taenite half-widths are large, but slower cooling rates near the end of the growth when half-widths are small.

References: [1] Goldstein et al. (2009) MaPS 44, 343-358 [2] Yang et al. (2010) GCA 74, 4493-4506 [3] Goldstein et al. (2014) GCA 140, 297-320 [4] Yang et al. (2008) GCA 72, 3043-3061 [5] Hopfe and Goldstein (2001) MaPS 36, 135-154 [6] Dauphas (2007) MaPS 42, 1597-1613 [7] Lyons et al. (2019) MaPS (Accepted) [8] Crank (1984) Clarendon Press, 425 p. [9] Lyons et al. (2018) Goldschmidt, 1625

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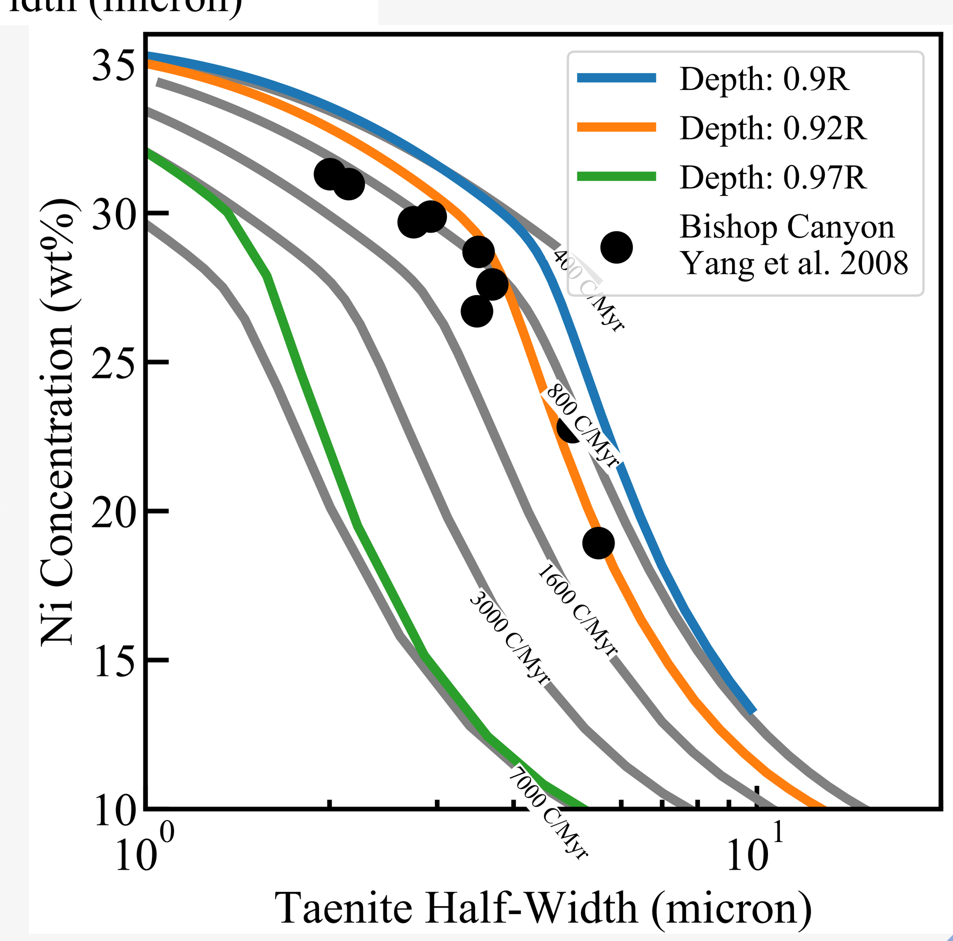
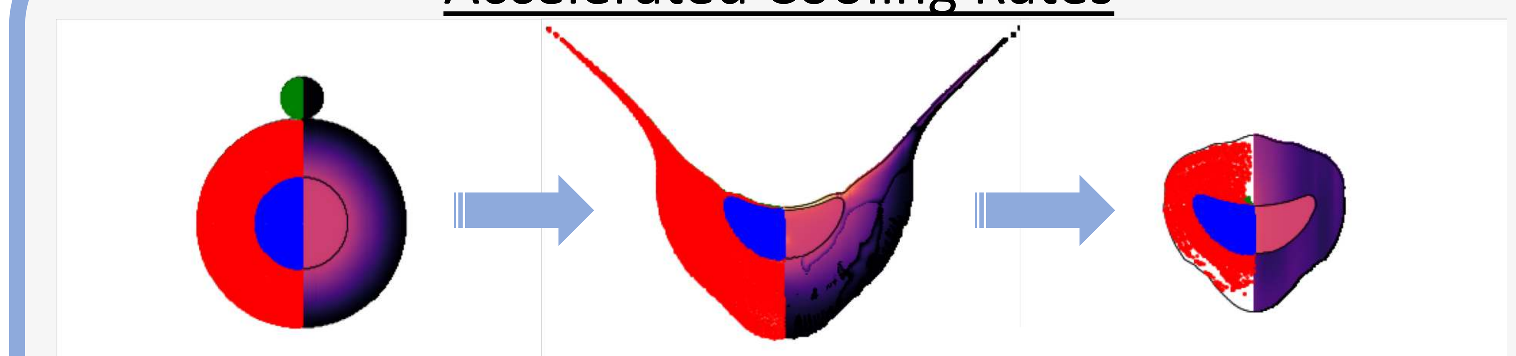
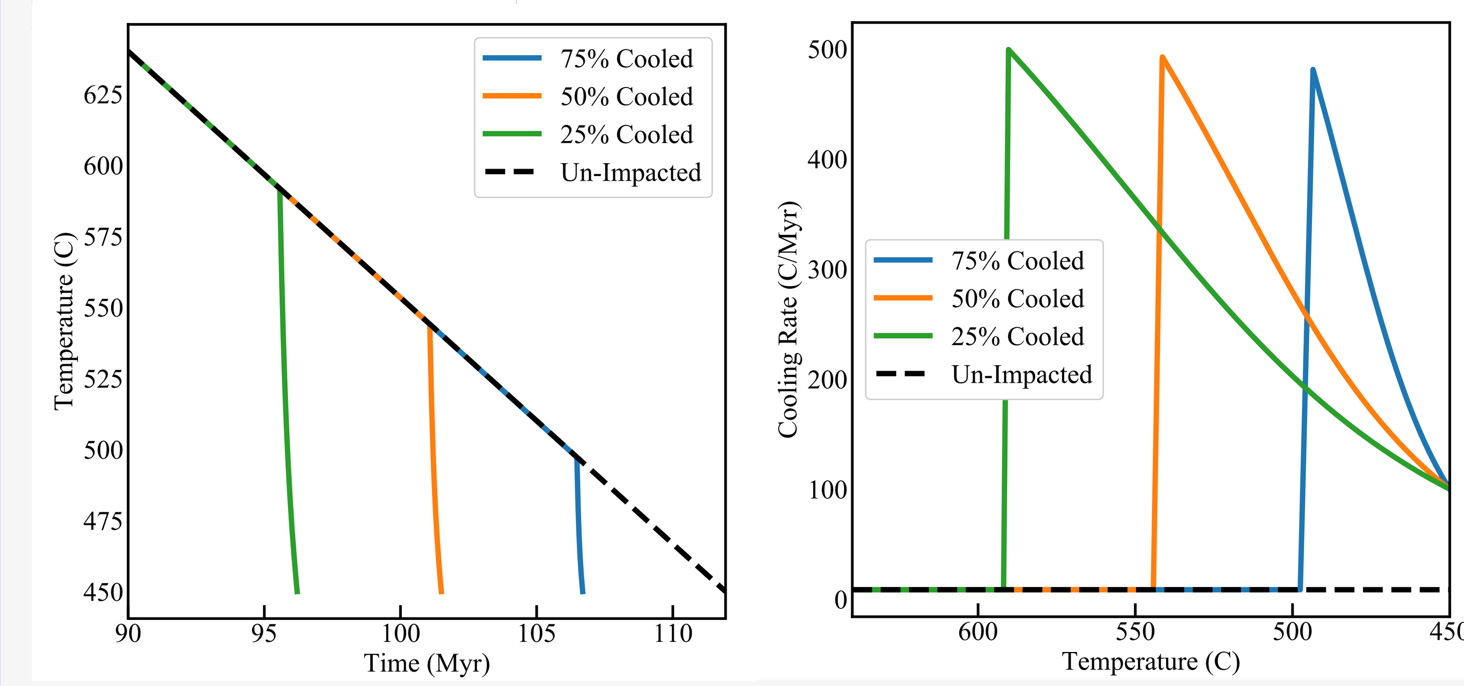
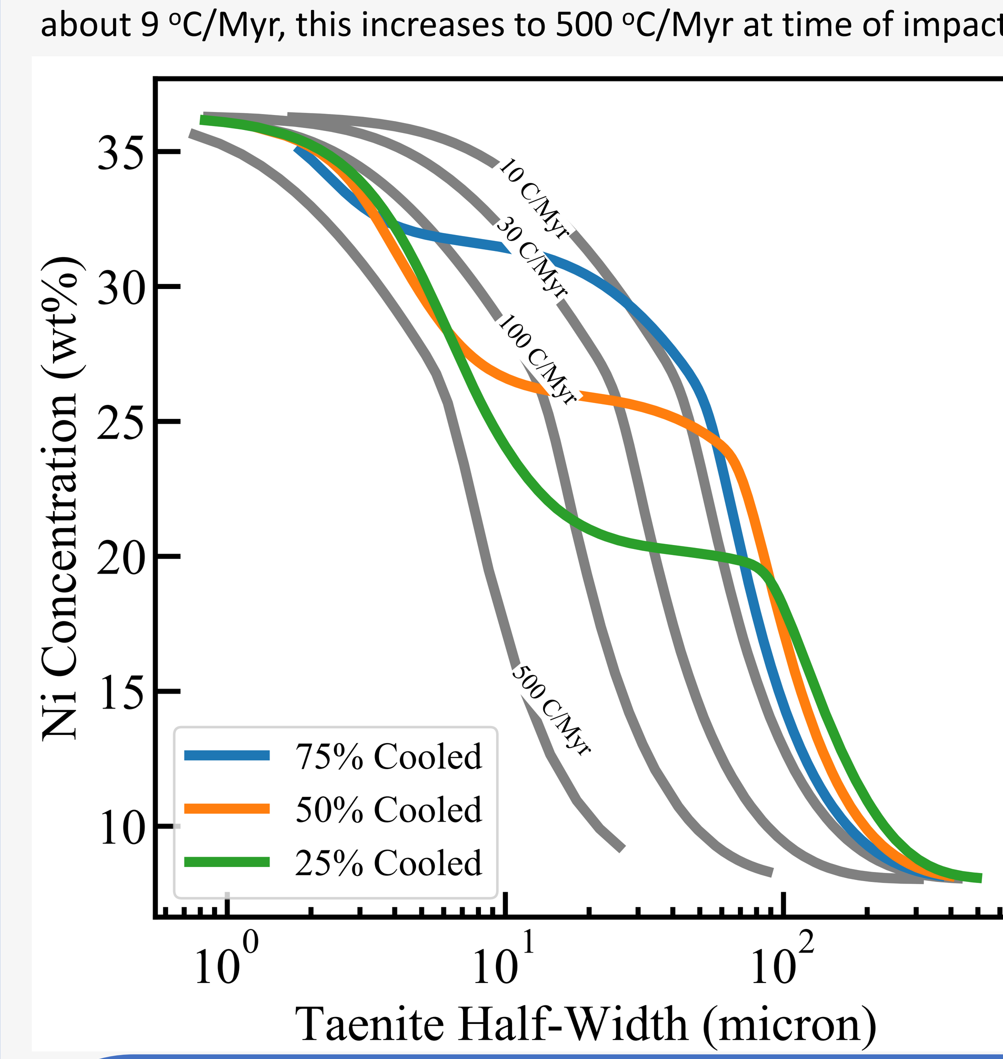


Accelerated Cooling Rates





Impacts do not need to strip away the entire mantle to accelerate the cooling of iron meteorites. More common, energetic impacts between planetesimals can uplift and/or disperse the core nearer to the surface of the body (as seen in the above impact time series), accelerating cooling rates by several orders of magnitude [7]. Parameterized examples of such impacts can be seen above for a 100 km radius body after about 100 Myr of cooling. Impacts occur when the iron has cooled through 25, 50, and 75% of the Widmanstätten pattern formation temperature range (640–450 °C). The initial cooling is about 9 °C/Myr, this increases to 500 °C/Myr at time of impact which slows to 100 °C/Myr.



The Wood diagrams for the associated cooling curves are shown to the right. At large half-widths, the curves match that of the pre-impact cooling rate. The curves transition to faster cooling rates when the impact occurs. At small half-widths, the final cooling rate is most closely matched.

Conclusions

- **Impacts onto differentiated planetesimals can significantly increase and alter the cooling histories of iron meteorites.**
- **Here we have shown the extent to which the Widmanstätten pattern is sensitive to these changes, with non-monotonic cooling producing different Ni-Concentration vs Taenite Half-Width relations than traditional constant cooling rate models.**
- **Systematic variations between data and constant cooling model predictions may be signs that a given meteorite parent body experienced impacts early in its history. Our results provide a quantitative means of evaluating changes in thermal evolution caused by impacts, and the types of impacts that may have occurred.**