

A NEW HYPOTHESIS FOR THE EVOLUTION OF IIE IRON METEORITES BASED ON GEOCHRONOLOGY AND PETROLOGY OF THE MILES METEORITE. R. S. Kirby¹, P. L. King¹, R. W. Henley¹, U. Troitzsch¹, T. R. Ireland¹, M. Turner², ¹Research School of Earth Sciences, Australian National University, Acton ACT 0200, Australia, ²Research School of Physics and Engineering, Australian National University, Acton ACT 0200, Australia.

Introduction: The Miles IIE iron meteorite contains ubiquitous silicate inclusions consisting of Na- and K-feldspars, high-Mg pyroxenes, tridymite, Na-Al-K-Si rich glass, phosphates and accessory oxide minerals. It is one of fourteen IIE iron meteorites that contain abundant silicate inclusions [1]. These meteorites are unlikely to have formed in a planetary core; however, their origin is unresolved. Existing hypotheses for their origin include extreme differentiation within a parent body [e.g. 2], melting and mixing of a parent body through surface impacts [e.g. 3], catastrophic destruction of an asteroid followed by re-accretion [e.g. 4], and unusual nebular condensation and subsolidus nebular processing [e.g. 5]. This study provides a new hypothesis for the formation of IIE iron meteorites through a systematic approach of geochemical and petrological studies.

Methods: The petrology and mineralogy of the silicate inclusions, as well as the surrounding Fe, Ni metal, schreibersite ($[\text{Fe,Ni}]_3\text{P}$) and metal grain boundaries were characterized in 2-D with optical reflectance and scanning electron microscopy (SEM) at the Centre for Advanced Microscopy (CAM), Australian National University (ANU). X-ray microcomputed tomography (μCT), conducted at the Research School of Physics and Engineering, ANU, was used for 3-D characterization. Mineral chemistries were determined using, and quantitative SEM Energy Dispersive Spectroscopy (EDS) at CAM, ANU, with calibrated standards. Crystallography was determined with X-ray Diffraction (XRD) at the Research School of Earth Sciences (RSES), ANU. $^{207}\text{Pb}/^{206}\text{Pb}$ were obtained on zirconium oxide and phosphate minerals was conducted with the Sensitive High Resolution Ion Microprobe – Reverse Geometry RSES, ANU.

Results: Key results include the distribution and textural relationships of silicate and metallic phases throughout the meteorite. Three immiscible phases are identified – a metal, a silicate and a phosphate phase. Metallic phases (Fe, Ni metal, schreibersite and FeS) make up 20 vol.% of the meteorite with the remainder comprised of silicate, phosphate and oxide minerals. Kamacite is the primary metal phase forming <1cm grains with triple-point boundaries [6] (Fig. 1). Minor taenite is present as irregular-shaped grains. There is no Widmanstätten pattern.



Figure 1: Map of one of the samples used in the study. Silicate/phosphate inclusions are shown in black, metal grain boundaries in grey and schreibersite in red. Schreibersite is concentrated along the grain boundaries.

Most silicate inclusions are interconnected by conduits along the metal grain boundaries around which schreibersite is concentrated (Fig. 1). Albite ($\text{Ab}_{93}\text{Ab}_4\text{Or}_3$), K-feldspar ($\text{Or}_{92}\text{Ab}_7\text{An}_{<1}$), augite ($\text{En}_{48}\text{Wo}_{41}\text{Fs}_{11}$), enstatite ($\text{En}_{80}\text{Fs}_{18}\text{Wo}_2$) and tridymite are the primary silicate minerals. Calcium phosphates (chlorapatite and merrillite) are always associated with silicates and commonly form lobate features that extend from the silicate inclusions into the surrounding metal (Fig. 2).

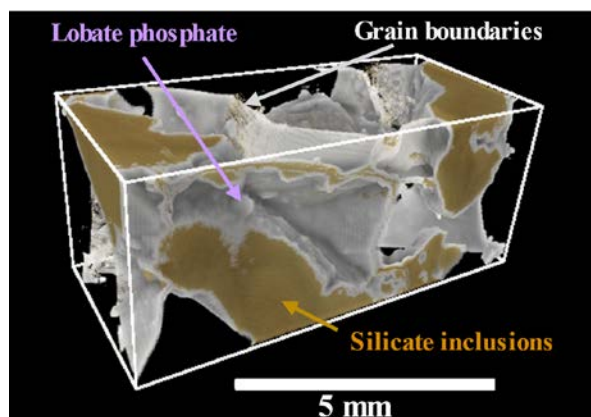


Figure 2: Tomogram showing the geometry of a section of the Miles IIE iron meteorite. The metal portion has been stripped away so that the grain boundaries (grey ribbon-like features) and silicate inclusions are visible (beige areas). Lobate phosphates can be seen extending from the margins of the silicate inclusions.

Zirconium oxide minerals, including zirconolite and srilankite were found to have high levels of uranium and low common Pb. Baddeleyite had low U, as had apatite. All analyses are consistent with a single

formation age of 4542 ± 2 Ma as determined by ^{204}Pb -corrected $^{207}\text{Pb}/^{206}\text{Pb}$, although the weighted mean is dominated by the srilankite analyses (Fig. 3).

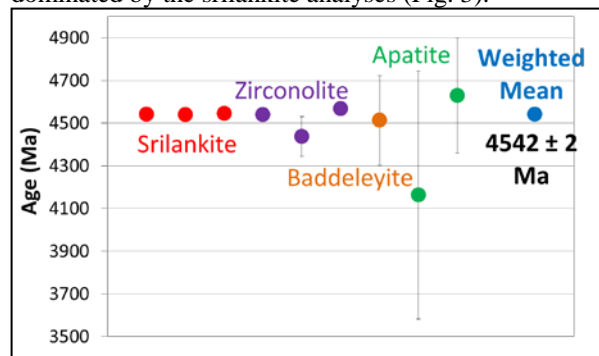


Figure 3: In-situ SIMS $^{207}\text{Pb}/^{206}\text{Pb}$ dates. Error bars are present on all dates however in some cases error bars are smaller than symbols.

The compositions of mineral phases provide evidence for a high temperature process of formation. Based on the stability of tridymite, the stability of ferropseudobrookite in equilibrium with metallic iron, and the Fe-Ni-P metal solidus the likely maximum temperature during formation would have been 1068 - 1470°C.

Discussion: Data presented in this study provides a new hypothesis for the evolution of the Miles and other IIE iron meteorites. These meteorites formed under reducing conditions whereby Fe, Ni metal and silicates separated during high temperature differentiation from an initially Fe-rich silicate parent material. This process is analogous of the smelting of iron oxides.

Phase distribution and chemistry provide evidence for high temperatures and the formation of three immiscible phases. Such conditions may occur when an initial Fe-rich silicate parent material undergoes gas-solid-melt reactions driven by the loss of thermal energy from the molten parent material. Under reducing conditions FeO is reduced to metallic iron, immiscible Ca-phosphate phases form and volatile elements are sequestered into a silicate melt phase. Rapid cooling then occurred preserving the three immiscible phases and textural relationships via dissipation of heat through gas flow along grain boundaries.

Schreibersite is concentrated along grain boundaries through a series of melt-melt and P-rich gas-melt reactions. During the formation of immiscible phosphates CaO is removed from the silicate melt, decreasing its basicity (i.e. the $\text{CaO}/[\text{Na}_2\text{O} + \text{K}_2\text{O}]$ ratio). This reduces the activity of phosphate, promoting the reversion of phosphorus into the melt [7]. Schreibersite can also form through the alloying of phosphorus in Fe-Ni metal through the reaction of iron with phosphorus gas [8]. Grain boundaries act as conduits for silicates and

gas therefore reactions would occur along them, thus explaining the distribution of schreibersite.

Volatile elements such as sodium and potassium appear enriched in the silicate inclusions. However, if Fe concentration is not admitted as a variable, because it has separated from the silicates during the high temperature melting process, then the relative concentrations of other elements in the Miles meteorite and CI chondrite follow a similar pattern (Fig. 4) [9]. This is consistent with the siderophile elements partitioning into the immiscible metallic melt and Ca, P and Cl partitioning into the immiscible phosphate melt.

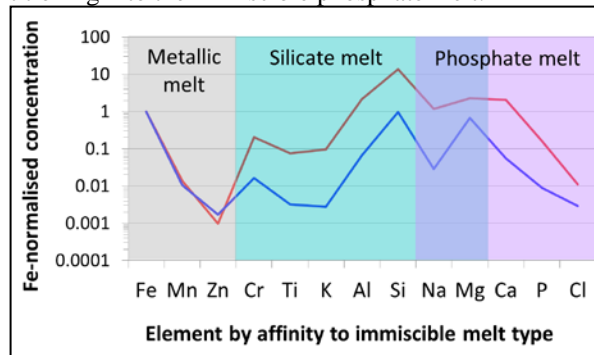


Figure 4: Composition of CI chondrite (blue) and silicate inclusions in the Miles meteorite (red) normalised to Fe content.

Conclusions: This study provides a new hypothesis on the evolution of the Miles IIE iron meteorite. Phase distribution and chemistry provide evidence for high temperature differentiation from an initially Fe-rich silicate parent material analogous of the smelting of iron oxides. This hypothesis is based on the formation of three immiscible phases during gas-solid-melt reactions driven by the loss of thermal energy from molten parent material. This research demonstrates that iron meteorites can form through processes other than core-formation.

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