Metamorphism in mesosiderites revisited: (I) Mount Padbury Enclaves and the thermochronological implications of tridymite.

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Introduction:— Metamorphism in the mesosiderites has been long recognized [1], and its effects produce much of the observed petrological and chemical complexity in the group. It also provides the basis for classification schemes [2-5]. The age of metamorphism in mesosiderites is unknown. Conflicting estimates based on differing chronometers exist, in part because the scale of isotopic measurements is not well matched with the scale of petrological evidence. This mismatch results in mixing ages from overlapping lithologies.

While mafic clasts in mesosiderites have been documented widely [6-11] the effect of metamorphic overprinting on the chemical and isotopic composition of those mafic clasts has not been systematically treated. We document a pair of mafic clasts from Mount Padbury and discuss how their compositions likely changed in response to thermal overprinting and propose tridymite as a an Ar/Ar chronometer for dating thermal metamorphism.

Mount Padbury 'Enclaves': Several mafic clasts, also called 'enclaves,' in Mt Padbury were described [1, 12, 13] as the products of igneous fractionation that subsequently suffered varying degrees of thermal overprinting or metamorphism. Mt Padbury is classified as a Type 1A mesosiderite that has undergone little metamorphism [3, 4]. We discuss here two of these clasts (U and Z [after 1]) that exemplify the 'slight' metamorphism previously observed [1]

Clast Z is a ferroan unbrecciated subophitic clast that was considered [1, 12] to be unmetamorphosed although the pyroxene is loaded with fine 'clouding', a product of late stage thermal overprinting [14]. The mineralogy of this clast is dominantly pigeonite/augite (mostly $En_{30}Wo_{3}$ to $En_{26}Wo_{39}$) and anorthite ($An_{88-91}Or_{0.2}$) with lesser tridymite and various opaque minerals [12]. However a second population of more magnesian pyroxene ($En_{40}Wo_{6}$-$En_{43}Wo_{40}$) occurs intergrown with tridymite (SiO_2). [Figure 1a]. The tridymite is as K-rich (1000-2000 ppm) as the plagioclase [Figure 2a]. We will call these intergrown areas A-T pockets.

Within clast Z, small areas of pyroxene and tridymite form a distinctive lithic variant that resembles the equilibrium assemblage formed at the eutectic minimum for the system olivine-plagioclase-SiO_2 [15].

We suggest, therefore, that these pockets represent eutectic partial melts of the augite-enriched clast material that formed subsequent to the original crystallization of the clast as a distinct lithology.

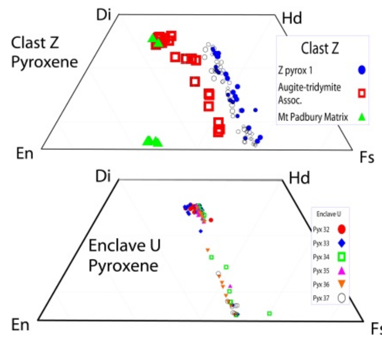


Figure 1: (a)Clast Z pyroxene with A-T pocket and matrix. (b) Clast U pyroxene

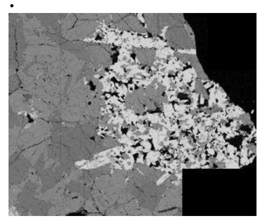
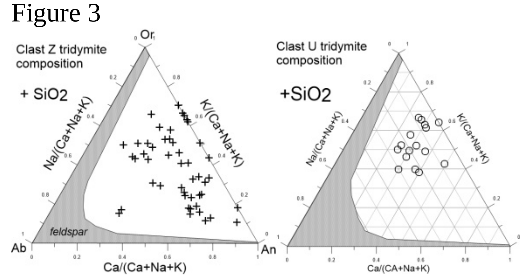


Figure 2: Si-Kα map of Augite-tridymite (A-T) pocket in clast U: white=tridymite, greys= augite, pigeonite & plag; black=oxides & holes

Figure 3



The A-T pockets may be products either of a thermal metamorphic overprint or of a late-stage shock imprint. Crosscutting of the A-T pockets by the clast edges, however, seems inconsistent with a post-assembly shock melting event.

The presence of significant levels of potassium in the associated tridymite raises the possibility that the pockets will be datable and that their ages will supplement those derived from the analysis of plagioclase for the large clast Z.

The pyroxene compositions (Figure 1a) of the A-T pockets become more magnesian with distance from the more ferroan main portion of Clast Z. A similar reverse zoning effect is known from more magnesian mafic clasts in mesosiderites [16] and reflects partial diffusive exchange of Mg and Fe between the clast mafic phases and the mesosiderite matrix mafics. The Fe/Mn systematics for A-T melt pockets in Clast Z are also displaced from those of the main pyroxene (Figure 3) suggesting either reduction [of Fe] or exchange [of Fe/Mn,Mg] with the mesosiderite matrix, which has a low Fe/Mn ratio. We conclude that clast Z despite an unmetamorphosed appearance [1], is significantly modified by the presence of eutectic melt pockets and subsolidus exchange of Fe, Mn and Mg with the mesosiderite matrix.

***Clast U*-**gabbro is also a ferroan unbrecciated clast but is granular and homogeneous ($En_{40}Wo_{3}$-$En_{31}Wo_{40}$: An_{89-91}) (Figure 1b). Again, like Clast Z, it contains one A-T pocket (Figure 2b), but otherwise presents little evidence of a metamorphic overprint. The tridymite in Clast U is as K-rich as the surrounding plagioclase, implying that it likely hosts measurable radiogenic ^{40}Ar.

Metamorphic effects: The variability of composition and texture observed for the two clasts U and Z is broadly similar to that previously reported for many other ferroan mafic clasts in mesosiderites [9-12]

The pyroxene in Clast U show only subtle compositional effects attributable to metamorphic exchange with mesosiderite matrix. Accordingly, clast U will be treated as an example of a relatively unmetamoprhosed clast. Neither the pyroxene composition range (Figure 1b) nor the Fe-Mn-Mg systematics of clast U deviates significantly from the typical eucritic ranges.

In contrast, ferroan clast Z is partially modified compositionally. Pyroxene associated with the A-T pockets is clearly more magnesian than pyroxene in the bulk of the clast (Figure 1). Two possible explanations for this unusual Mg enrichment are: (a) reduction of Fe from the clast pyroxene (b) exchange of Fe and Mg between clast pyroxene and the more magnesian matrix pyroxene (Figure 1). Possibly both mechanisms act in concert. A consequence of Fe-reduction is also seen

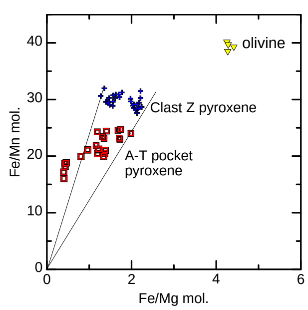


Figure 4: Fe-Mn-Mg systematics for Clast Z with Fe redox tie-lines

in the Fe-Mn-Mg systematics of clast Z (Figure 4). A-T pockets (red) have significantly lower Fe/Mn ratios than does the coexisting clast pyroxene (blue) suggesting that the formation of the A-T pockets involved reduction of Fe from the clast silicates and liberation of free SiO_2. ($FeSiO_3 > SiO_2 + Fe + O$). This excess SiO_2 moves the minimum melt for the system to move the the eutectic qtz-pyx-plag[15]

Implications for mesosiderite chronology: The formation of mafic clasts and their later metamorphic overprinting are two important milestones in the history of mesosiderites. It is desirable to date these events and other later ones, which may include brecciation. Clasts U and Z and others like them present an opportunity for such dating. The ferroan clasts of Clast U type appear to be relatively unaltered and contain K-bearing plagioclase, a phase well suited to Ar/Ar dating of the time of crystallization from a magma.

The A-T pockets found in both Clasts U and Z, in contrast, show signs of alteration and contain K-rich tridymite, a phase well suited to Ar/Ar dating of the time of thermal metamorphism.

For dating , we follow the approach of [17] by physically separating plagioclase from the main clast and tridymite from the A-T pockets and analyzing each separately.

The presence of two radiogenic Ar hosts in each clast that can be dated independently permits further exploration of the cooling rate of mesosiderite mafic clasts at magmatic/metamorphic temperatures. Thermochronological studies to determine the closure temperature for plagioclase and tridymite coupled with apparent ^{40}Ar-^{39}Ar ages are in progress, and may bracket the cooling rates discussed by [6] to more tightly constrain the thermal history of these mafic clasts.

References:

1. **McCall**, G.J.H., Mineral. Mag 1966 **35**: 1029 ***2***. **Powell**, B.N., GCA, 1969 **33** 789 ***3.*** **Powell**, B.N., GCA 1971 **35** 5. ***4***. **Floran,** R.J., Proc Lunar Planet Science Conference, 1978. **9th** 1053. **5. Floran,** R.J., et al. 1978 Proc. Lunar Planet. Sci. Conf. 9th: 1083. ***6***. **Bogard**, D.D., et al., GCA 1990. **54**: 2549. ***7***. **Bogard**, D.D.et al., *Lunar and Planetary Science Conference*. 1988,112. ***8***. **Haack,** H.,et al Meteoritics, 1992. **27** 229. ***9***.**Mittlefehldt**,D., Meteoritics, 1978. **13**: p. 566. ***10.*****Mittlefehldt,** D.W., GCA, 1979. **43** 1917. ***11***.**Mittlefehldt**, D.W., GCA, 1990. **54**: 1165. ***12***.**Ikeda**,Y.,M.et al., Proc NIPR Symposium on Antarctic Meteorites, 1990.**3**:99. ***13***.**Delaney**, J.S., et al., *LPSC*. 1982. 152-153. ***14***.**Harlow, G.E.** and **R. Klimentidi**s, Proc LPSC, 1980. **11th**: 1131. ***15***. **Longhi**, J. & V. **Pan**, *LPSC*. 1988. p. 459-470. ***16***. **Delaney**, J.S., et al., Proc L PSC, 1981. **12B**: 1315 ***17***.**Lindsay**, F.N., et al., E-PSL, 2015. **413**: p. 208