A SURVEY OF METAL MICROSTRUCTURES IN THE VACA MUERTA MESOSIDERITE. G. Zachén[1], P. Lindgren[1], C. Alwmark[1] and L. Daly[2]. [1]Department of Geology, Lund University, 223 62 Lund, Sweden, Email: nat15gza@student.lu.se [2]School of Geographical & Earth Sciences, University of Glasgow, Glasgow, G12 8QQ, UK

Introduction: The mesosiderites, part of the stony-iron meteorite group, are polymict, cataclastic breccias composed of a mixture of generally equal amounts of metal and silicates. The silicate portion of mesosiderites include clasts of gabbro, basalt, and pyroxenite, which are thought to be derived from the crust of evolved, differentiated parent bodies, while the metal portion of mesosiderites are thought to originate from the core of evolved bodies, and is composed of native iron and nickel [3]. The formation history of mesosiderites, in particular the specific process of the metal-silicate mixing event, has been the subject of debate [1,2]. The current prevailing theory is that a molten core impacted the crust of an evolved body [4].

The mesosiderite iron-nickel metal show intricate microstructures including the Widmanstätten exsolution lamellae, composed of Ni-poor α-phase (e.g. kamacite) and Ni-rich γ-phase (e.g. taenite, tetrataenite or awaruite); the latter of which accommodates a large span of nickel concentrations, depending on temperature [5]. A thorough understanding of the metal microstructures is important since they can be used as tracers of the formation, deformation and cooling history of the mesosiderite parent body.

Aim of study: This study has focused on the metal microstructure in a sample of the Vaca Muerta mesosiderite, a find from the Atacama Desert in Chile [6]. Our overall aim was to systematically describe the different types of metal microstructures present across a section using electron backscatter diffraction (EBSD) and chemical etching, and to discuss their possible origins.

Methods: A rounded metal nugget from the mesosiderite Vaca Muerta of approximately 2 cm in diameter was cut, mounted in resin and polished to EBSD standard. The sample was then coated with 5 nm of carbon prior to scanning electron microscopy - backscatter electron (SEM-BSE) imaging, energy dispersive x-ray spectroscopy (EDS) analyses and electron backscatter diffraction (EBSD) analyses using a Tescan Mira3 High-Resolution Schottky Field Emission (FE)-SEM at Lund University. BSE images, EDS and EBSD data were collected using the Aztec software package from Oxford Instruments. The accelerating voltage was 20 kV. EBSD maps were acquired at a tilt angle of 70°. Areas representing the major metal textures were mapped at an appropriate step size to ensure sufficient sampling. The EBSD data were processed using the Channel 5 Software package from Oxford Instruments including a single wildspike correction to remove noise, and a sequential 8 and 7 point iterative nearest neighbor zero solution. The data were also cleaned to remove systematic misindexing related to the high symmetry of the cubic metal phases. After the completion of SEM microanalyses, the sample was etched with nital (5% nitric acid, 95% ethanol) [7], and re-analyzed.

Results and discussion: The most striking microstructure is the characteristic Widmanstätten patterns (WP), that are composed of α-phase bands, usually with widths of around 100 µm, adjacent to lamellae of γ-phase bands with widths of ca. 10 µm; tetrataenite and taenite, or awaruite phases could not be discerned using EBSD as they have identical crystal systems. The WP is a result of extremely slow cooling, over millions of years, primarily observed in the iron meteorites [8]. The WP are further arranged into subzones, which are oriented differently from each other, within relict taenite crystals (Fig. 1a). This is the dominant texture of the sample. However, there are a few cases where this texture is interrupted by broader WP with α-phase bands of up to 200 µm, and γ-phase bands of up to 10 µm (Fig. 1a). These broader cross cutting bands have a different orientation to the dominant microstructure. At the interfaces between WP subzones the γ-phase bands broaden in the direction of the interface (Fig. 1a). From the EBSD maps, it can be seen that the α-phase bands in both the thin and the broad WP lamellae are composed of subgrains with 1-4° misorientations between subgrains. The γ-phase bands almost always have the same orientation (Fig. 1b). In some locations in the sample the γ-phase does not exhibit a linear structure but form round features. It is likely that these round features are not part of the WP and have formed by some other process (Fig. 1c). Hopfe and Goldstein [9] discussed various explanations for inaccuracies in predicting the Ni-content in the central parts of the taenite. During our studies of the WP we noted that γ-phase bands sometimes looked like they were in the process of splitting (Fig. 1b). This might be another source of error when measuring width and the Ni-concentration in the central parts of the taenite, as bands may have split at one point.

The other striking millimeter-sized microstructure in the metal is composed of a ca 500 µm – 1 mm sized interconnected blebs of the α-phase (Fig. 1d). This structure forms a bulbous film draping the outline of what is likely the original metal crystals (now domains of WP). These α-phase blebs often contain central inclusions of troilite, schreibersite, merrillite, chromite and silicates including plagioclase, pyroxene, and SiO_2. The mineral inclusions are central in the structure, and the shape of the α-phase blebs follow the shape of the inclusions. Due to the blebs' positions and shapes, they are most likely interstitial textures, i.e. amalgamations of eutectic phases. The fact that each of the blebs are single-crystal α-phases is puzzling. The γ-phases inside the interstitial spaces also have a different orientation relative to the WP γ-phases. Taken together with the blebs' bulbous shapes, this might imply that the interstitial spaces were remelted at some point, followed by recrystallization, which created a second generation of γ-phases in a separate orientation. Had the interstitial spaces not been remelted, we would expect the interstitial γ-phases to have the same orientation. The increased amount of chalcophile and lithophile phases, as well as a greater amount of grain boundaries present in the interstitial spaces, would then have promoted the exsolution of α-phases [10]. The fact that the α-phase crystals in the blebs are larger than the ones in WP might be due to a different mechanism of exsolution.

In the etched sample, microstructures on the nanoscale appeared due to preferential etching of α-phases, in larger γ-phase masses (Fig. 1e). The central parts of these masses most likely represent what in the literature is referred to as the "cloudy zone" (CZ), and the rim of this cloudy zone is the so-called "outer taenite rim" (OTR) [5]. These microstructures are likely due to spinodal decomposition, which is a solid immiscibility texture between α- and γ-phases at low temperatures [5]. The spinodal microstructure range from nanometer-micrometer sized isolated blebs to worm-like networks. The boundary between the cloudy zone and the OTR is sharp, but there is an additional nanometer-sized web-like structure in the γ-phase, spanning throughout the CZ and into the OTR (Fig. 1f).

Summary: Microstructures from the millimeter- to nanometer scale have been studied and described in a metal nodule from the Vaca Muerta mesosiderite. Our observations are interpreted in the context of formation mechanisms.

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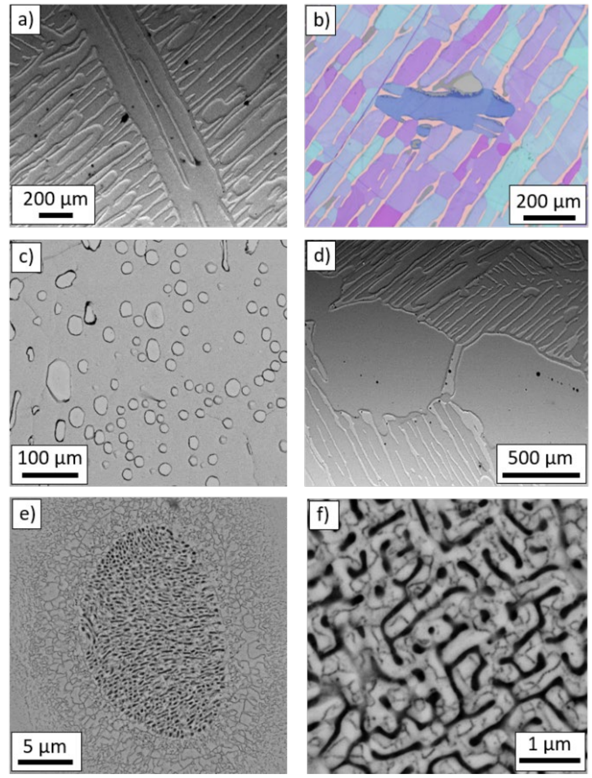

Fig. 1. (a) SEM-BSE micrograph showing WP of α-phase bands (dark grey) and γ-phase bands (light grey). Note widening of γ-phase bands at interface between the WP subzones. **(b)** inverse pole figure (IPF) colored EBSD map showing orientation of α-phase (purple to light blue) and γ-phase (beige). **(c)** SEM-BSE micrograph showing round features of γ-phase (light grey) in α-phase (dark grey). **(d)** SEM-BSE micrograph showing interconnected blebs of the α-phase (dark grey). **(e)** SEM-BSE micrograph of etched sample showing CZ (dark interior) and OTR (speckled rim) in the γ-phase. **(f)** SEM-BSE micrograph of etched sample showing spinodal decomposition (black and light grey texture) and an additional nanometer-sized web-like structure, both in the γ-phase.

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