NORTHWEST AFRICA 14758 AND 15507: CLUES FOR EVOLUTION OF ANGRITE'S PARENT BODY.
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Introduction: Northwest Africa (NWA) 14758 and 15507 are two of the five angrites reported in Meteoritical Bulletin, No. 111 [1]. NWA 14758 is a plutonite mainly made up of olivine, with early reports on its petrography and mineralogy by Irving and Carpenter [2]. NWA 15507 is a plutonite dominated by anorthite. Lowers et al. [3] preliminarily discussed the crystallization history on its anorthite.

We prepared a thin section for each of the two angrites, and then obtained their major element X-ray maps using the TESCAN Integrated Mineral Analyzer. After that, image processing and machine learning methods were combined for identifying and labeling the phases in the sections. Finally, we used the Electron Probe Micro-analyzer and related equipment to determine the quantitative composition of the major minerals.

NWA 14758: Fourteen phases were found in NWA 14758. By incorporating the weathering products back into their original forms, and removing those phases that were clearly produced by falling and terrestrial processes, we obtained its original volume abundance: 78.4% olivine, 18.8% clinopyroxene, 1.5% spinel, 0.9% kamacite, 0.3% anorthite, and 0.1% troilite. The entire sample is well-crystallized, with no observable compositional zoning in any of the minerals.

Kamacite has a composition of $Fe_{92}Ni_{8}$. It occurs in two forms: (1) euhedral crystals and (2) veins of varying width. Some veins extend along the boundaries of silicate grains, and others cross-cut the silicates, showing a complex history of metal-silicate mixing. The fine veins have been almost completely oxidized, while larger crystals retain some unoxidized metal. Among the oxidation products, wüstite is the predominant one (Ni seems to be lost during the oxidation process), and a minority of iron is distinctly oxidized to the ferric state.

The chemical formula of olivine is $Ca_{0.03}Mg_{1.22}Fe_{0.73}Si_{1.00}O_{4}$, with trace amounts of Mn. Compared to well-preserved olivine, those close to the metal veins (which have been oxidized) and unfilled cracks tend to be weathered, leading to depletion of Mg and Si. Unlike the description by Irving and Carpenter [2], we found kirschsteinite near the troilite, although it is rare.

Spinel has a composition of $Mg_{0.50}Fe_{0.55}Cr_{0.13}Al_{1.82}O_{4}$, with trace amounts of Ti. Anorthite often appears around it, indicating the reaction of clinopyroxene + spinel = olivine + anorthite (Fig. 1). Some isolated grains of anorthite may be entirely transformed from spinel.

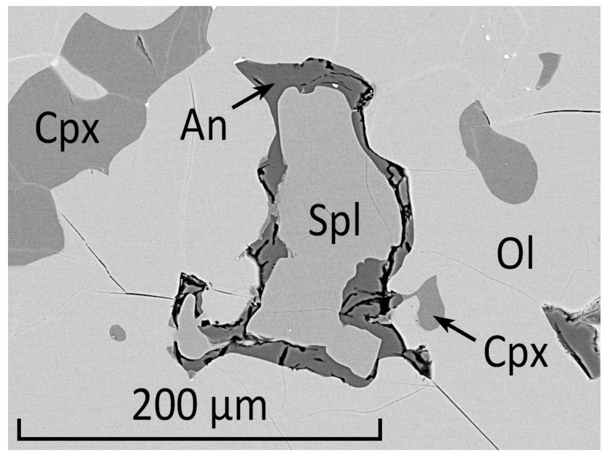

Fig. 1. Backscattered electron (BSE) image of NWA 14758, showing the reaction at the edges of spinel to form anorthite. Spl = spinel, An = anorthite, Ol = olivine, Cpx = clinopyroxene.

The remaining phases with simple morphology and mineralogy include: clinopyroxene ($Ca_{0.96}Mg_{0.66}Fe_{0.19}Al_{0.54}Ti_{0.12}Si_{3.53}O_{6}$, with trace amounts of Cr); anorthite ($Ca_{0.96}Fe_{0.04}Al_{1.96}Si_{2.03}O_{8}$, with trace amounts of Na); and troilite sporadically distributed among the silicates. Through the morphology and contact relationships of the minerals, we can infer the sequence of initial crystallization: spinel and kamacite → olivine and clinopyroxene → anorthite and troilite.

NWA 15507: Using a process similar to that described above, we determined the abundance of igneous minerals in NWA 15507: 71.6% anorthite, 16.7% olivine, 10.1% clinopyroxene, 0.8% merrillite, 0.6% troilite, 0.2% spinel, and 0.1% kamacite. This sample is also well-crystallized, but some minerals show compositional zoning. This may suggest a faster cooling than that of NWA 14758.

Olivine exsolves into two homogeneous phases: the main body of olivine ($Ca_{0.06}Mg_{0.76}Fe_{1.12}Si_{1.02}O_{4}$) and kirschsteinite as exsolution lamellae ($Ca_{0.92}Mg_{0.27}Fe_{0.77}Si_{1.01}O_{4}$), both containing trace amounts of Mn. In some locations near the main olivine, kirschsteinite coheres to form grains. Additionally, the mineral assemblage of kirschsteinite + anorthite + hedenbergite is observed in symplectites, apparently as the decomposition product of Al-rich augite (Fig. 2).

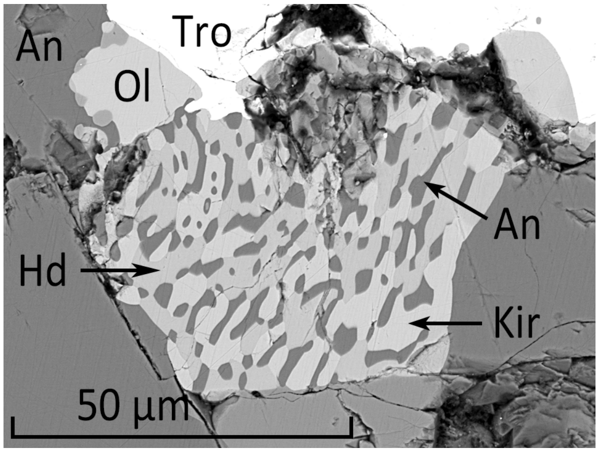

Fig. 2. The BSE image of a symplectite in NWA 15507. An = anorthite, Ol = olivine, Tro = troilite, Kir = kirschsteinite, Hd = hedenbergite.

The composition of clinopyroxene varies widely. For clarity, we divide it into augite (Al-rich) and diopside/hedenbergite (Al-poor). A reference composition for the augite is $Ca_{1.00}Mg_{0.54}Fe_{0.30}Al_{0.36}Ti_{0.04}Si_{1.77}O_6$ (n=3, with trace amounts of Cr). From core to rim, Al and Ti increase, while Mg and Si decrease, with no obvious changes in Ca and Fe. The diopside and hedenbergite appear in symplectites or in the late-stage assemblages of spinel + clinopyroxene + troilite, corresponding respectively to the decomposition of augite (Fig. 2) and the crystallization of late-stage melts (Fig. 3).

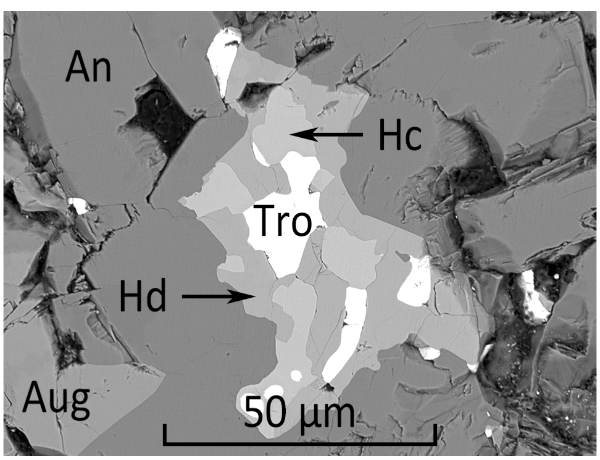

Fig. 3. The BSE image of a late-stage assemblage in NWA 15507. Tro = troilite, Hc = hercynite, Hd = hedenbergite, An = anorthite, Aug = augite.

Spinel occurs in two forms and corresponding compositions: (1) Ceylonite, which crystallized from magma, varying from Mg- to Fe-rich. A reference composition for the Fe-rich ceylonite is $Mg_{0.29}Fe_{0.75}Al_{1.96}O_4$ (n=3, with trace amounts of Cr and Ti). (2) Hercynite, found in late-stage assemblages, with significant Fe(III) but without Mg (Fig. 3).

The remaining phases with simple morphology and mineralogy include: anorthite ($Ca_{0.99}Al_{1.93}Si_{2.05}O_8$, with trace amounts of Fe); merrillite ($Ca_{9.86}Na_{0.09}Mg_{0.56}Fe_{0.19}Si_{0.29}P_{6.77}O_{27.70}F_{0.30}$); kamacite, which may be the first phase to crystallize from late-stage melt, often enclosed by troilite; troilite in some cases contains ~30 mol% NiS, but the majority is Ni-free. Through the morphology and contact relationships of the minerals, we infer the sequence of initial crystallization to be: anorthite → olivine → merrillite and augite → kamacite → troilite, spinel, and diopside/hedenbergite.

Implications: As a plutonic rock, NWA 14758 is composed mainly of olivine, with a higher kamacite abundance and Mg-Fe ratio, less anorthite and troilite, and no phosphates. Moreover, its spinel contains significant Cr, and the pyroxene shows no chemical zoning. This evidence suggests that it is an early, slowly cooled cumulate. In contrast, NWA 15507 may have formed from the crystallization of an evolved magma at a shallower place. This study enriches the database of angrites, and deepens our understanding of the angrite parent body. Future research could focus on more in-depth characterization and analysis of these two meteorites, or try to find a more diverse range of angrite samples.

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References: [1] J. Gattacceca, et al. (2023) Meteoritics & Planetary Sci. 58, 6, 901-904. [2] A. J. Irving, P. K. Carpenter. (2022) 80th Meteorit. Soc. Mtg. #6366. [3] H. Lowers, et al. (2023) Microscopy and Microanalysis, 29 (Suppl. 1), 836-837.