NORTHWEST AFRICA 4898: A NEW HIGH-ALUMINA MARE BASALT FROM THE MOON. Ansgar Greshake[1], Anthony J. Irving[2], Scott M. Kuehner[2], Randy L. Korotev[3], Marko Gellissen[4], and Herbert Palme[4], [1]Museum für Naturkunde, Humboldt-Universität zu Berlin, 10115 Berlin, Germany (ansgar.greshake@rz.hu-berlin.de), [2]Department of Earth and Space Sciences, University of Washington, Seattle, WA 98195, USA, [3]Department of Earth and Planetary Sciences, Washington University, St. Louis, MO 63130, USA, [4]Institut für Geologie und Mineralogie, Universität zu Köln, 50674 Köln, Germany.

Introduction. Apart from lunar rocks and soils returned by the Apollo and Luna missions and data obtained from various lunar orbiters, meteorites from the Moon are a valuable source of information on its formation and geological evolution. Of the 58 unpaired lunar meteorites recovered so far, the majority are regolith or fragmental breccias, and only very few are unbrecciated mare basalts [1]. We report here on a new type of high-alumina mare basalt from the Moon.

Mineralogy and Petrography. NWA 4898 is a single 137 g individual stone almost completely covered with fusion crust that was found at an undisclosed location in 2005. The meteorite shows a dominantly intergranular texture with large euhedral to subhedral olivine megacrysts or clusters of crystals set into a groundmass of chemically zoned pigeonite and augite as well as plagioclase (maskelynite) laths (Fig. 1a,b). Opaque phases include abundant needle and sometime skeletal shaped ilmenites, mostly euhedral chromites, and rare troilite and Fe-Ni metal. A pure SiO_2-phase (probably cristobalite) is present dominantly at the grain boundaries between plagioclase and the mafic minerals. Many regions of the rock have a pronounced spherulitic appearance due to sprays of clinopyroxene and plagioclase (Fig. 1a,b). No phosphates or Zr-rich phases were found.

Olivine megacrysts are compositionally zoned and often contain chromite and/or melt inclusions (Fig. 1a,b). Sometimes olivine and pyroxene clump together to form glomerophyric textures. Pyroxenes are compositionally zoned and mostly subhedral to prismatic pigeonite and augite. Some clinopyroxenes are very Fe-rich; orthopyroxene is not present in the sections studied. Due to shock metamorphism plagioclase is completely converted into maskelynite. The grains predominantly occur as chemically zoned laths or blocky crystals generally exhibiting sharp boundaries to the neighboring minerals. Some maskelynite grains poikilitically enclose pyroxene. In the sprays the maskelynite is present as small interstitial grains in between pyroxene (Fig 1a). Among the opaque phases ilmenite is by far the most abundant. The mostly needle shaped grains often nucleate on the crystals faces of olivine and crosscut the primary texture of pyroxene and plagioclase. Chromite typically occurs as euhedral grains either enclosed in olivine (Fig. 1a) or as separate, chemically zoned grains or clusters of grains in the matrix (Fig. 1d,e).

Mineral compositions. Representative analyses of phases in NWA 4898 are given in Table 1. Olivine megacrysts have Fe-poor cores ($Fa_{26.3}$; FeO/MnO = 75.8; CaO = 0.26-0.82 wt.%) and Fe-rich rims ($Fa_{44.1}$; FeO/MnO = 151; CaO = 0.28-0.38 wt.%). Pigeonite ranges from $Fs_{25.1-44.8}Wo_{10-19.9}$ (FeO/MnO = 47.6-73.4; TiO_2 = 0.55-1.32 wt.%) and augite from $Fs_{25-58.7}Wo_{20.2-38.3}$ (FeO/MnO = 44.4-76.3; TiO_2 = 0.76-2.23 wt.%). Rare ferroan pyroxenes have $Fs_{72.4-75.6}Wo_{10.8-23.9}$ and FeO/MnO = 70.8-74.4. The maskelynite laths are essentially K-free $An_{91.9-96.5}$ and contain minor amounts of SrO (0.02 wt.%). Elemental mapping reveals a symmetric zoning of Al and Ca in the laths (Fig. 1c). The small spherulitic maskelynites are compositionally in a much narrower range ($An_{91.9-96.5}Or_{0.3}$) and contain up to 0.08 wt.% SrO. Spinel is mostly titanian chromite with Cr/(Cr+Al) = 0.581, Mg/(Mg+Fe) = 0.226, and TiO_2 = 2.25 wt.% overgrown by chromian ulvöspinel with Cr/(Cr+Al) = 0.581, Mg/(Mg+Fe) = 0.226, and TiO_2 = 23 wt.%; the contact between core and rim is commonly sharp rather than continuous (Fig. 1e).

Chemical composition and age. Bulk analyses by XRF spectrometry and INAA yielded: (in wt.%) SiO_2 46.15, TiO_2 2.39, Al_2O_3 11.98, Cr_2O_3 0.43, FeO 17.34, MnO 0.25, MgO 8.31, CaO 11.43, Na_2O 0.30, P_2O_5 <0.06; (in ppm) Ni <180, Co 24.8, V 120, Sc 65.4, Zr 145, La 4.71, Ce 14.8, Nd 12, Sm 4.55, Eu 0.997, Tb 1.06, Yb 4.00, Lu 0.570, Hf 4.45, Ta 0.24, Th 0.44.

The REE pattern shows a negative Eu anomaly [2], and a Rb-Sr crystallization age of 3.58 Ga was determined by [3].

Shock metamorphism. All minerals in the meteorite show signs of strong shock metamorphism. Olivine displays multiple sets of planar and irregular fractures and strong mosaicism. Plagioclase is completely converted into maskelynite, pyroxene and chromite are intensely fractured, and ilmenite shows twinning. The specimen is crosscut by shock veins which appear yellowish in transparent light. The veins often show fluidal textures and contain larger mineral fragments. More rarely, local melting of mostly pyroxene and melt pockets with sulfide droplets are present. According to [4] the meteorite belongs to shock stage 2b, and experienced an equilibration shock pressure of ~28-34 GPa and a post-shock temperature of ~200-250°C.

Discussion and conclusions. Based upon its texture and mineral composition, NWA 4898 initially solidified in a thick lava flow or a magma chamber at shallow depths with the following crystallization sequence: spinel → olivine → pigeonite → augite → plagioclase → ilmenite (together with ulvöspinel overgrowth) → SiO_2-polymorphs. The sprays of plagioclase and clinopyroxene then formed during quenching from the residual melt while the basalt was quickly erupted or came in contact with cold neighboring rocks. The bulk chemistry resembles that of Apollo 14 and Luna 16 high-alumina basalts [5], except that NWA 4898 is significantly more evolved [Mg/(Mg+Fe) = 0.271]. We thus conclude that this meteorite is an unusually young high-alumina mare basalt from the Moon.

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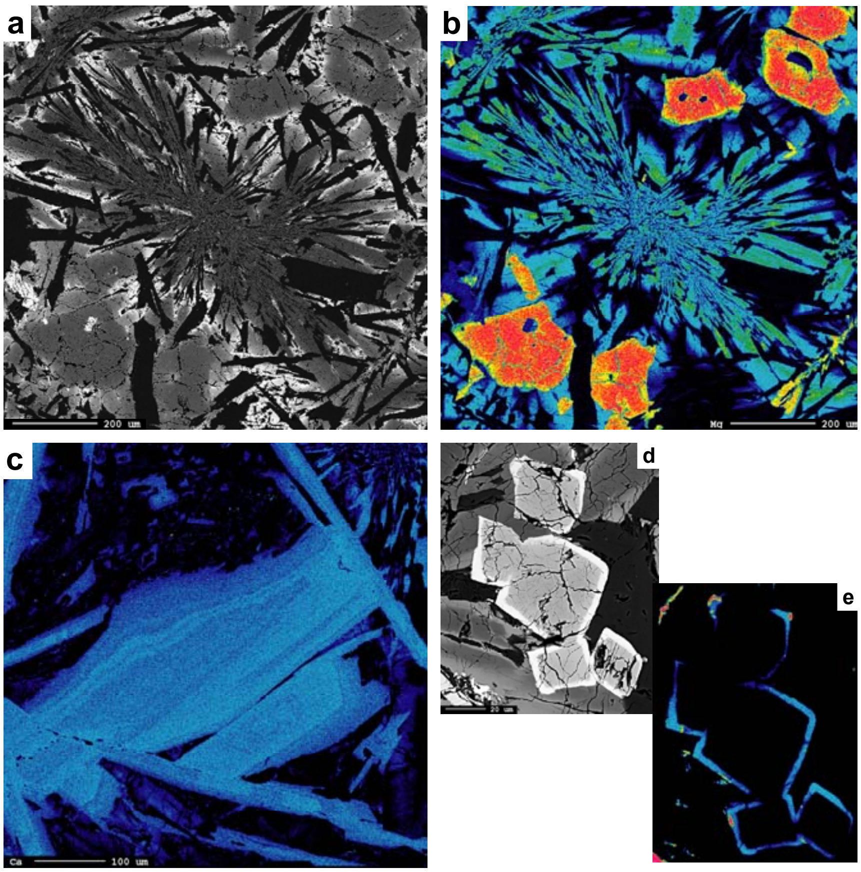

Fig. 1. (a) BSE image of a typical texture in NWA 4898. (b) MgKά-elemental map of the same region: olivine megacrysts and a spray of pyroxene and maskelynite are dominant. (c) CaKά-elemental map of maskelynite showing symmetric zoning. (d) BSE image of a cluster of zoned chromites. (e) The TiKά-elemental map shows the ulvöspinel rim of the grains.

Table 1. Representative analyses of mineral phases in NWA 4898.

	ol core	ol rim	pigeonite	augite	augite	mask lath	chro core	chro rim
SiO_2	38.4	36.3	52.5	49.0	46.6	44.8	0.08	0.15
TiO_2	b.d.	0.05	0.55	1.95	1.99	0.04	2.25	20.5
Al_2O_3	b.d.	0.03	2.31	4.04	2.36	34.0	20.2	7.3
Cr_2O_3	0.2	0.07	0.7	0.87	0.09	n.d.	44.4	16.3
FeO	23.9	37.7	16.9	14.8	32.0	0.54	23.8	52.1
MnO	0.24	0.25	0.38	0.22	0.53	b.d.	0.23	0.48
MgO	37.1	26.8	20.6	12.1	3.6	0.3	9.0	3.11
CaO	0.29	0.28	6.2	17.6	13.6	19.2	b.d.	0.1
Na_2O	b.d.	b.d.	b.d.	0.03	0.04	0.46	0.05	b.d.
K_2O	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Total	100.13	101.48	100.14	100.61	100.81	99.34	100.01*	100.04*
Fa	26.5	44.1						
Fs			27.5	25.1	57.3			
Wo			12.9	38.3	31.1			
An						96.0		

Data in wt%; *normalized to 100%; b.d.: below detection limit