NWA 2999, A UNIQUE ANGRITE WITH A LARGE CHONDRITIC COMPONENT. M. Gellissen[1], H. Palme[1], R. L. Korotev[2] and A. J. Irving[3], [1]Institut für Geologie und Mineralogie, Universität Köln, Zülpicher Str. 49B, D-50674 Köln, Germany, (m.gellissen@uni-koeln.de), [2]Department of Earth and Space Sciences, Washington Un iversity, C/B 1169, Saint Louis, MO 63130 (korotev@wustl.edu) [3]Dept. of Earth & Space Sciences, University of Washington, Seattle, WA 98195 (irving@ess.washington.edu)

Introduction: The desert meteorite find NWA 2999 was classified as an angrite based on mineralogy, mineral chemistry and oxygen isotopes [1]. Because of unique P, T conditions recorded in the mineralogy of NWA 2999, [1] suggested that this meteorite is from the Mercurian mantle, implying that Mercury is the angrite parent body. We report here the first chemical data for NWA 2999. These data confirm an angrite origin of NWA 2999, but also indicate differences in chemistry and composition of NWA 2999 to other angrites, making this a unique meteorite.

Texture, mineralogy and oxygen isotopes: NWA 2999 has an overall plutonic, polygonal-granular texture (similar to Angra dos Reis and LEW 86010), but with distinctive large anorthite, spinel and recrystallized olivine porphyroclasts and discontinuous anorthite coronas around spinel grains, a mineral assemblage absent in other angrites. Orthopyroxene, kirschsteinite and vesicles are absent [1]. The oxygen isotopic composition of NWA2999 is typical of angrites [2].

Chemistry: The bulk chemical composition of NWA 2999 was determined by XRF on a 120 mg sample, according to procedures described by [3]. Results are given in Table 1, along with other angrites recently analysed. The bulk composition determined here is very similar to that estimated from mineral chemistry and modal mineralogy by [1]. Trace elements were determined on a different sample by INAA on five 30 mg subsamples. Average concentrations and standard deviatons calculated from the results are given in Table 2, for analytical procedures see [4]. INAA and XRF are in good agreement for Cr, the INAA values for Ni and Fe are higher than those for XRF, suggesting less metal in the sample analysed by XRF.

The major element composition of NWA is unique when compared to other angrites (Tables 1, 2, 3). The MgO content of NWA 2999 is with 19.0 % higher than that of average angrites (10.9 %), although there is a significant spread in individual MgO analyses of angrites, with LEW 87051 reaching a similar MgO level as NWA 2999 (Fig. 1, Table 3). At the same time NWA 2999 is about 15 % lower in SiO_2. The refractory elements CaO, Al_2O_3 and TiO_2 are more than 50 % lower in NWA 2999, the subchondritic Al/Ti ratio of NWA 2999 is typical of all angrites. The total iron content in NWA 2999 is with 31.2 % FeO (Fe_{tot} as FeO) much higher that of all other angrites (av. 20.2 %). This is the result of the presence of abundant FeNi-metal in NWA 2999, which is very low or absent in other angrites. From the excesses in Fe and Ni an approximately chondritic Fe/Ni ratio of the FeNi alloy is estimated, in agreement with LA-ICPMS data on metal [5]. The INAA data indicate about half of the chondritic level of Ir, Au, Ni and Co. Such high contents were never encountered in angrites. The very low contents of Na and Se (a proxy for S), are typical of all angrites (Table 2).

Interpretation: The high Ni, Co, Ir and Au contents (Table 2) would indicate that NWA 2999 contains a primitive meteoritic component. This is supported by the high Mg and Cr in NWA 2999. The low refractory element contents in NWA 2999 would then represent dilution of normal angrite material with meteoritic material. We have performed mixing calculations of average angrite (Tab. 3) with various types of chondritic meteorites. The mixing ratio was based on Ni. This leads to 30 to 50 % of a chondritic component, depending on the type of meteorite. Although these models produce the right trend, in detail they provide only a poor fit to the chemistry of NWA 2999, i.e., the low contents of Ca, Al and Ti in NWA 2999 require more than 70 % of a primitive metreoritic component. In addition, if NWA 2999 is a mixture of an APB (Angrite-parent-body) lithology and a chondrite then NWA 2999 should be much richer in volatile elements such as alkalis and S, which is not the case (Table 2). Also, such a high content of a chondritic component should be visible in oxygen isotopes.

An alternative view is to take both components from the same parent body. A differentiated lithology with elevated Ti, Ca, Al and REE, but with low Mg, Cr and almost no Ni and Ir is mixed with a core-mantle component, high in Mg, Cr, Fe, Ni, Au and Ir of the same parent body. Both components are then equilibrated at some depth to produce the metamorphic texture of NWA 2999. Mixing could be the result of a large impact on the APB.

In a more sophisticated model an iron meteorite would hit the angrite parent body and mix mantle and crustal lithologies.

In the latter two models the approximately chondritic ratio of excess Mg and Fe would be fortuitous. An additional constraint is given by the low P of NWA

2999. The "chondritic component" did apparently not contain P. The present metal in NWA 2999, has approximately chondritic Ni/Co and Fe/Ni ratios, judging from bulk chemical data and analyses by [5], but it cannot contain P. Loss of P by metal-silicate equilibration must have occurred before metal was incorporated in NWA 2999, indicating that the metal is processed.

References [1] Kuehner S.M.et al. (2006) *LPS XXXVII*, Abstract #1344. [2] Irving A.J. et al. (2005) *EOS Trans. AGU 86, Fall Meeting Supplement,* Abstract #P51A-0898. [3] Wolf D. and Palme H. (2001) *MAPS 36*, 559-572. [4] Korotev R.L. et al. (2006) *GCA 70,* 5935-5956. [5] Humayun M. et al. (2007) *LPS XXXVIII*, Abstract #1221. [6] Kurat G. et al. (2003) *GCA 68,* 1901-1921. [7] priv. comm. Weckwerth G. [8] Wolf D. PhD Thesis (2001). [9] Mittlefehldt, D.W. & Lindstrom, M.M. (1990) *GCA 54,* 3209-3218. [10]: Yanai, K. (1994) *Proc NIPR Symp Antarc Meteorites 7,* 30-41. [11] Warren, P.H. et al. (1995) *Antarc Meteorites 20,* 261-264.

Table 1.
Oxide- and trace-element concentrations for some Angrites.

	NWA 2999 (1)	D'Orb. (1)	SAH 99555 (2)	±
SiO_2	33,4	36,9	38,6	0,35
TiO_2	0,42	0,85	0,88	0,01
Al_2O_3	4,71	12,3	12,9	0,20
FeO	31,2	24,9	25,6	0,40
MgO	19,0	6,45	6,79	0,13
MnO	0,24	0,25	0,27	0,01
CaO	7,37	15,2	15,4	0,06
P_2O_5	< 0,1	0,17	0,18	
V	172	575	95	20
Cr	2480	316	266	50
Ni	4670	28*	50**	500/*,** 30

Values in cg/g (%), except V, Cr and Ni in µg/g (ppm). All iron reported as FeO. ± = estimated analytical uncertainty. D'Orb = D'Orbigny.
Measurement by: (1) this work, * [6], ** [7], (2) [8].

Table 2. Mean results of INAA for 5 subsamples of NWA 2999 with a total mass of 167 mg.

	conc.	SD	±		conc.	SD	±
Na	56	9	4	Nd	<7		
Sc	20.9	1.0	0.2	Sm	0.67	0.07	0.007
Cr	2340	160	25	Eu	0.236	0.019	0.017
Fe	26.1	1.2	0.3	Tb	0.177	0.016	0.011
Co	360	40	4	Yb	0.77	0.04	0.02
Ni	6200	800	100	Lu	0.120	0.005	0.003
Se	1.3	0.6	0.2	Hf	0.58	0.06	0.03
Br	0.60	0.19	0.12	Ta	<0.1		
Zr	<100			W	<1.2		
Sb	<0.05			Ir	0.250	0.044	0.003
Cs	<0.2			Au	0.032	0.006	0.001
Ba	220	70	7	Th	<0.2		
La	0.80	0.26	0.02	U	0.13	0.07	0.05
Ce	2.0	0.5	0.5				

Values in µg/g (ppm) except Fe in cg/g (%). SD = Standard deviation of the 5 values. ± = Estimated analytical uncertainty (1σ) on a single measurement.

Table 3.
Oxide- and trace element concentrations for more Angrites.

	ADR (1)	LEW 86010 (1)	LEW 87051 (1)	A 881371 (2)	av.
SiO_2	43,7	39,6	40,4	37,3	39,4
TiO_2	2,05	1,15	0,73	0,88	1,09
Al_2O_3	9,35	14,1	9,19	10,1	11,3
FeO	9,8	18,2	19,4	24,0	20,2
MgO	10,8	7,0	19,4	14,8	10,9
MnO	0,10	0,20	0,24	0,20	0,21
CaO	23,1	18,4	10,4	12,5	15,8
P_2O_5	0,13	0,13	0,08	0,17	0,14
Cr	1505	820	1100	890	816
Ni*	58	39	45	114	56

Values in cg/g (%), except Cr and Ni in µg/g (ppm). All iron reported as FeO. ADR = Angra dos Reis. av. = average of Angrites of Tab. 1 and 3, except NWA 2999. Data taken from: (1) [9], (2) [10], * [11].

Figure 1.

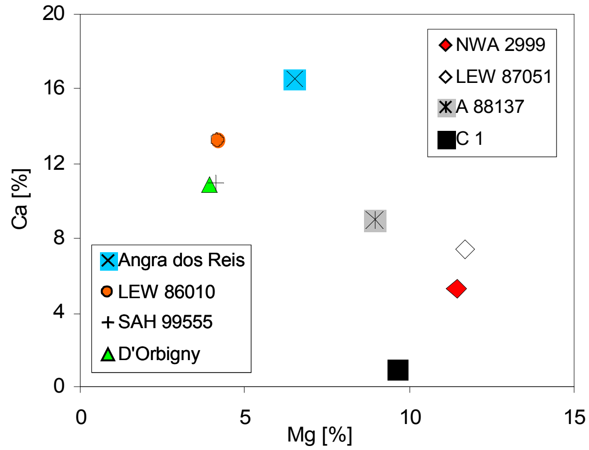

Figure 2.