Science AAAS

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Supporting Online Material for

Paleocene-Eocene Thermal Maximum and the Opening of the Northeast Atlantic

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Published 27 April 2007, *Science* **316**, 587 (2007)
DOI: 10.1126/science.1135274

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SUPPORTING ONLINE MATERIAL

MATERIALS AND METHODS

SANIDINE FUSION AGES (Tables S1 and S2)

Sanidine crystals from the SF Tuff were analyzed at QUADLAB, Roskilde University (Table S1). Samples were irradiated for 60 hours in the Cd-shielded RODEO position at the HFR reactor in Petten, Netherlands along with Fish Canyon Sanidine, using a published reference age of 28.02 Ma [*Renne et al.*, 1998], as the neutron flux monitor mineral and previously degassed K-glass chips in order to determine the reactor production ratio $(^{40}Ar/^{39}Ar)_K$. Single and multiple sanidine grains were fused using a 50 watt Synrad CO_2 laser attached to a small volume (450 cc) all metal extraction line. Sample cleanup was achieved by utilizing two water-cooled SAES GP-50 getter pumps and a cryo-cooled cold finger. The argon isotopic analyses were made on a NU-Instruments multicollector Noblesse noble gas mass spectrometer, equipped with a faraday detector and three ion-counting electron multipliers. An advantage of multicollection is that it can reduce the errors introduced through signal decay and sequential measurement of different isotopes species on a single collector instrument. The sanidine analyses were carried out by measurement of ^{40}Ar and ^{39}Ar on the faraday detector, ^{37}Ar on the axial ion counter and ^{36}Ar on the low mass ion counter, with baselines being measured for each cycle. Blank measurements were made between each fusion analysis, typical values being $< 1 \times 10^{-16}$ moles for M/e 40 and $<5 \times 10^{-18}$ moles for M/e 36. Combined instrumental mass fractionation and detector discrimination for the $^{40}Ar/^{36}Ar$ ratio (^{40}Ar on the faraday/^{36}Ar on the low mass ion counter) was corrected for by repeated measurement of 1.2×10^{-13} mole air aliquots from a calibrated air pipette. An instrumental fractionation factor of 1.005 AMU was determined by measuring 1.2×10^{-12} mole air aliquots on the faraday detector only, and was used to correct the $^{40}Ar/^{39}Ar$ ratio. Interference isotopes produced during irradiation were corrected using previously published values [*Renne et al*. [1998], except for $(^{40}Ar/^{39}Ar)_K$ which was determined here by analysis of co-irradiated outgassed K-glass to be $\sim 5 \pm 0.5$ $(x10^{-3})$.

Sanidine from the Danish –17 Ash was analyzed at Rutgers University (Table S2). Crystals were loaded into individual sample wells of aluminum irradiation disks, along with aliquots of the irradiation monitor mineral Fish Canyon Sanidine. The loaded sample disks were wrapped in Al foil, sealed in quartz glass tubes, and then irradiated for 40 hours in the Cadmium-Lined, In-Core Irradiation Tube (CLICIT) facility of the Oregon State University Triga Research Reactor (OSTR).

Calibration and determination of the irradiation parameter J was determined by multiple total fusion analyses of the co-irradiated monitor mineral Fish Canyon Sanidine: $J = 0.010514 \pm 0.00000425$. Interference isotopes produced during irradiation of the samples using the Oregon TRIGA were corrected using previously published values $(^{36}Ar/^{37}Ar)_{Ca} = 2.72\pm0.06$ $(x10^{-4})$, $(^{39}Ar/^{37}Ar)_{Ca} = 7.11\pm0.02$ $(x10^{-4})$, $(^{38}Ar/^{37}Ar)_{Ca} = 1.96\pm0.08$ $(x10^{-5})$, $(^{38}Ar/^{39}Ar)_K = 1.22\pm0.02$ $(x10^{-2})$, $(^{40}Ar/^{39}Ar)_K = 7\pm3$ $(x10^{-4})$ [*Renne et al*. [1998] and *Deino et al.* [2002]. During the analysis of the samples and standards, mass discrimination was regularly monitored through measurement of air aliquots delivered via an on-line automated air pipette system and varied between 1.000 and 1.007 AMU. System baselines, Ar isotope backgrounds and mass discrimination measured for a typical sample loading and run period (approximately one week) were time averaged though linear regressions of the measured data. Resultant curves were then applied to the standards and unknown sample measurements. This approach of "modeling" baseline, background, and mass discrimination throughout the run period significantly improves the analytical data for both the standard and unknowns by minimizing spurious low signal measurements on backgrounds and blanks due to electronic and mechanical noise. Automation laser heating, gas extraction and clean-up, spectrometer measurement and data reduction were made using automated software written by A. Deino.

References:-

Deino, A., L. Tauxe, M. Monaghan and A. Hill (2002), $^{40}Ar/^{39}Ar$ geochronology and paleomagnetic stratigraphy of the Lukeino and lower Chemeron Formations at Tabarin and Kapcheberek, Tugen Hills, Kenya, *Journal of Human Evolution, 42*, 117-140.

Renne, P.R., C.C. Swisher, A.L. Deino, D.B. Karner, T.L. Owens and D.J. DePaolo (1998), Intercalibration of standards, absolute ages and uncertainties in $^{40}Ar/^{39}Ar$ dating, *Chemical Geology 145*, 117-152.

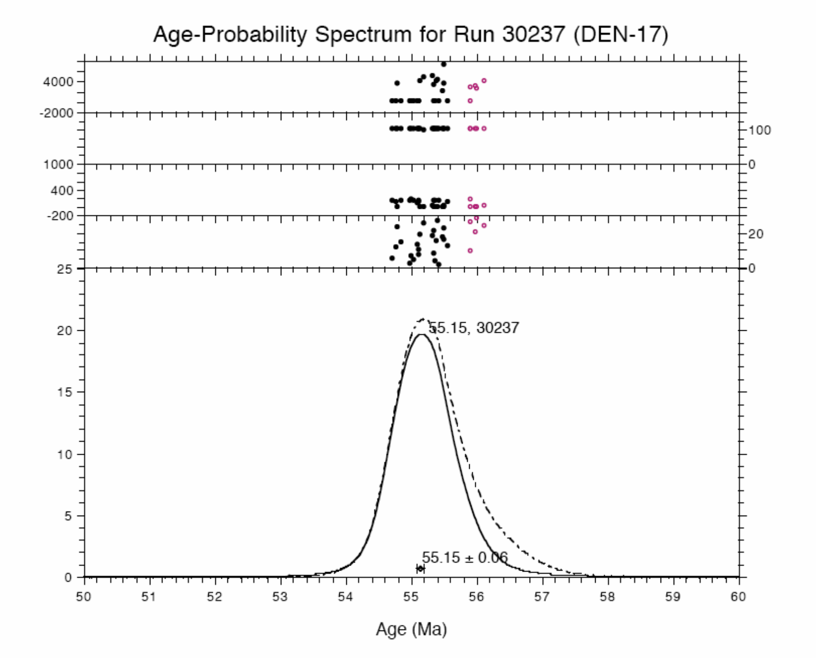

Fig. S1. Age –probability spectrum for sanidine analyses for Danish Ash -17. High age population (red circles) interpreted to represent xenocrysts.

TABLE S1. $^{40}Ar/^{39}Ar$ fusion ages for sanidines from the SF Tuff (sample 421564). Analyses carried out at QUADLAB, Roskilde University.

QUAD Lab #	$^{36}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{40*}Ar/^{39}Ar$	$\%^{40*}Ar$	Ca/K	^{39}Ar moles	Age (Ma)	± (1σ)
1303	0.000088	0.0082	1.640	98.5	0.017	1.3E-14	55.12	0.08
1309	0.000043	0.0052	1.643	99.3	0.011	2.0E-14	55.21	0.07
1311	0.000066	0.0052	1.642	98.8	0.011	2.0E-14	55.17	0.07
1313	0.000145	0.0075	1.640	97.5	0.015	2.1E-14	55.11	0.07
1330	0.000055	0.0037	1.647	99.0	0.008	3.0E-14	55.34	0.07
1332	0.000080	0.0110	1.636	98.6	0.022	3.5E-14	55.00	0.06
1334	0.000062	0.0072	1.638	98.9	0.015	2.8E-14	55.06	0.06
1336	0.000098	0.0117	1.639	98.3	0.024	3.5E-14	55.08	0.06
1338	0.000077	0.0080	1.636	98.7	0.016	1.8E-14	54.97	0.07
1351	0.000193	0.0126	1.613	96.7	0.026	1.0E-14	54.21	0.13
1353	0.000124	0.0035	1.637	97.8	0.007	4.2E-15	55.03	0.20
1357	0.000115	0.0054	1.639	98.0	0.011	5.4E-15	55.08	0.17
1359	0.000126	0.0117	1.638	97.8	0.024	8.5E-15	55.06	0.11
1361	0.000128	0.0086	1.643	97.8	0.018	9.4E-15	55.21	0.11
1364	0.000057	0.0059	1.642	99.0	0.012	2.0E-14	55.20	0.08

Arithmetic mean of 14 fusion ages for the SF Tuff (excluding analysis 1351) = 55.12 ± 0.06 Ma ($2\sigma_M$). Weighted mean = 55.12 ± 0.06 Ma. (2σ) J = 0.018916 ± 0.000019

TABLE S2. $^{40}Ar/^{39}Ar$ fusion ages for sanidines from Danish Ash -17. Analyses carried out at Rutgers University.

RU Lab #	**$^{36}Ar/^{39}Ar$**	**$^{37}Ar/^{39}Ar$**	**$^{38}Ar/^{39}Ar$**	**$^{40*}Ar/^{39}Ar$**	**%^{40}*Ar**	**Ca/K**	**^{39}Ar moles**	**Age (Ma)**	**± (1σ)**
30237-01	-0.000022	0.0039	0.01191	2.983	100.2	0.0076	9.2E-16	55.71	0.42
30237-02	-0.000149	0.0029	0.01186	2.983	101.5	0.0057	1.3E-15	55.71	0.31
30237-03	0.000053	0.0031	0.01238	2.931	99.5	0.0060	3.1E-16	54.76	1.23
30237-04	0.000029	0.0042	0.01218	2.946	99.7	0.0083	2.1E-15	55.02	0.20
30237-05	0.000053	0.0036	0.01204	2.939	99.5	0.0071	1.2E-15	54.91	0.34
30237-06	-0.000017	0.0041	0.01205	2.942	100.2	0.0080	1.5E-15	54.96	0.27
30237-07	0.000084	0.0031	0.01228	2.925	99.2	0.0061	1.4E-15	54.64	0.28
30237-08	0.000091	0.0048	0.01231	2.933	99.1	0.0095	7.5E-16	54.79	0.52
30237-09	0.000038	0.0036	0.01237	2.945	99.6	0.0070	4.2E-16	55.01	0.91
30237-10	-0.000010	0.0104	0.01234	2.940	100.1	0.0203	4.6E-16	54.92	0.84
30237-11	0.000087	0.0035	0.01208	2.963	99.2	0.0069	3.4E-16	55.35	1.11
30237-12	0.000115	0.0039	0.01220	2.945	98.9	0.0077	1.7E-15	55.02	0.23
30237-13	0.000026	0.0046	0.01197	2.932	99.8	0.0091	1.3E-15	54.78	0.30
30237-14	-0.000070	0.0042	0.01220	2.989	100.7	0.0082	8.7E-16	55.83	0.45
30237-18	0.000001	0.0040	0.01231	2.944	100.0	0.0079	8.8E-16	55.00	0.44
30237-21	0.000136	0.1381	0.01230	2.941	99.0	0.2707	3.0E-14	54.94	0.45
30237-22	0.000631	0.9628	0.01303	2.932	96.4	1.8871	4.5E-15	54.77	2.92
30237-23	0.000003	-0.1767	0.01234	2.945	99.5	-0.3464	1.8E-14	55.02	0.75
30237-24	0.000005	0.0189	0.01219	2.946	100.0	0.0371	4.3E-14	55.02	0.32
30237-25	0.000090	0.1576	0.01229	2.940	99.5	0.3089	3.4E-14	54.91	0.39
30237-26	0.000042	0.1407	0.01224	2.974	100.0	0.2758	2.6E-14	55.55	0.50
30237-27	0.000131	0.1739	0.01239	2.943	99.2	0.3408	2.7E-14	54.98	0.49
30237-28	-0.000050	0.0613	0.01195	2.977	100.7	0.1202	3.2E-14	55.60	0.42
30237-29	0.000035	0.0166	0.01217	2.956	99.7	0.0326	6.2E-14	55.22	0.22
30237-30	0.000074	0.1216	0.01220	2.942	99.6	0.2383	3.1E-14	54.97	0.45
30237-31	-0.000003	0.0439	0.01216	2.964	100.1	0.0861	3.4E-14	55.36	0.40
30237-32	0.000422	0.1218	0.01223	2.946	96.2	0.2388	4.1E-14	55.02	0.34
30237-33	0.000054	0.2389	0.01213	2.947	100.1	0.4683	2.1E-14	55.0	0.65

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30237-34	0.000034	0.1458	0.01232	2.981	100.1	0.2858	2.4E-14	55.67	0.57
30237-35	-0.000044	-0.0917	0.01199	2.953	100.2	-0.1797	3.6E-14	55.16	0.39
30237-37	0.000039	0.1985	0.01220	2.953	100.2	0.3890	2.2E-14	55.16	0.61
30237-38	0.000247	0.0335	0.01226	2.975	97.7	0.0657	5.6E-14	55.57	0.25
30237-40	-0.000008	0.0232	0.01217	2.954	100.1	0.0455	5.5E-14	55.18	0.26
30237-41	0.000116	-0.0368	0.01249	2.922	98.7	-0.0722	1.1E-14	54.59	1.19
30237-42	0.000213	0.1103	0.01214	2.938	98.2	0.2162	3.1E-14	54.89	0.44
30237-43	0.000193	0.2269	0.01220	2.921	98.7	0.4447	3.5E-14	54.57	0.40
30237-44	0.000022	0.0316	0.01233	2.978	99.9	0.0619	9.0E-14	55.62	0.19
30237-45	0.000014	0.0368	0.01241	2.967	100.0	0.0721	7.1E-14	55.42	0.21

Arithmetic mean of 38 fusion ages (N=38) for the Danish Ash -17 Tuff = 55.12 ± 0.12 Ma ($2\sigma_M$). Weighted mean = 55.18 ± 0.10 Ma (2σ).

J = 0.010514 ± 0.000004