GSA DATA REPOSITORY 2014201

Wotzlaw *et al.*, Towards accurate numerical calibration of the Late Triassic: High-precision U-Pb geochronology constraints on the duration of the Rhaetian

ANALYTICAL METHODS AND SUPPLEMENTARY DISCUSSION OF NEW U-PB GEOCHRONOLOGY RESULTS

A total of 43 analyses (see Tab. DR1) of single zircon crystals were performed employing chemical abrasion thermal ionization mass spectrometry techniques at the University of Geneva. Details of the chemical protocols, mass spectrometry and applied corrections are given in Schoene et al. (2010) and Wotzlaw et al. (2012; 2013). Data reduction and uncertainty propagation follow those described in McLean et al. (2011) and were performed employing the U-Pb_Redux software (Bowring et al., 2011).

Sample ***LP2010-1d*** (n=14): $^{206}Pb/^{238}U$ dates spread over ~0.9 Ma; youngest six zircon dates statistically equivalent with a weighted mean of 205.423 ± 0.043/0.68/0.23 Ma (MSWD [mean square weighted deviation]=1.6; Fig. DR1); $^{206}Pb/^{238}U$ date of youngest zircon (=maximum deposition age): **205.35 ± 0.19/0.20/0.30 Ma**.

Sample ***LP2010-1b*** (n=14): Yielded largest spread in $^{206}Pb/^{238}U$ dates of ~2.2 Ma; two distinct population with respect to Th/U (Fig. DR1). Interpreted to be a composite ash bed or composed of reworked volcaniclastic material, rather than being a primary air fall ash bed. $^{206}Pb/^{238}U$ date of the youngest zircon consistent with respect to its stratigraphic position relative the other two ash bed samples; maximum deposition age: **205.389 ± 0.095/0.11/0.24 Ma**.

Sample ***LP2010-3a*** (n=15): $^{206}Pb/^{238}U$ dates of main population spread over ~1.3 Ma; two analyses returned significantly older and discordant U-Pb dates; one grain yielded a significantly younger date of 204.31 ± 0.13 Ma; eight analyses of main population are statistically equivalent with a weighted mean $^{206}Pb/^{238}U$ date of 205.797 ± 0.054/0.076/0.23 Ma (MSWD=0.96; Fig. DR1); maximum deposition age: **205.70 ± 0.15/0.16/0.27 Ma**.

ADDITIONAL DETAILS OF BIVALVE BIOCHRONOLOGY

Sample ***3a****:* ~5 meters above uppermost *Monotis* bed; rare, small, largely fragmentary *Oxytoma* (n=5); only left valves (Fig. DR2). Similar to: (1) *Oxytoma* cf. *O. inaequivalvis* (Late Norian, Los Molles, coastal Chile, co-occuring with the ammonoids *Arcestes* and *Cladiscites,* Cecioni and Westermann, 1968; close to NRB, Quebrada Chaco, Northern Chile, co-occuring with Late Norian-early Rhaetian bivalve fauna, Chong and Hillebrandt, 1985); (2) *Oxytoma sp.* (Late Norian, *Cordilleranus* ammonoid zone, Pine Pass, British Columbia, Canada, Westermann, 1966; McRoberts, 2011).

Sample 3': ~5 metres further up section, abundant poorly preserved *Otapiria* (n>50; Fig. DR2); very thin-shelled; probably non-described species related to *Otapiria norica* (Late Norian, *Cordilleranus* ammonoid zone, northeastern British Columbia, Canada, McRoberts, 2011); ornament and outlines dissimilar to Rhaetian *Otapiria* (e.g., *"Otapiria?* cf. *O. ussuriensis"*, coastal Chile, Cecioni and Westermann, 1968; *O. dissimilis*, New Zealand, Marwick, 1953; *O. marshalli alpina*, western Tethys, Zapfe, 1973); also dissimilar to Carnian-early Norian *Otapiria* (e.g., southwest Japan, Ando, 1988; northeastern Russia, Kiparisova et al., 1966).

Table DR1. U-Pb isotopic data for Upper Norian ash beds from the Pucara basin

Figure DR1. Details of new zircon U-Pb geochronology from Upper Norian ash beds in the Pucara basin. (A) Zircon U-Pb data displayed in concordia space. Dashed lines display the uncertainty on the position of the concordia associated with ^{238}U and ^{235}U decay constant uncertainties. (B) Ranked $^{206}Pb/^{238}U$ dates corrected for initial ^{230}Th deficit. Alternative age interpretations are given for samples LP2010-1d and LP2010-3a. Black squares show the weight (in percent), with which individual analyses contribute to the weighted mean dates. Uncertainties are given at three levels of uncertainty propagation, ± X/Y/Z, where X represents analytical uncertainty only, Y includes tracer calibration uncertainties, and Z includes tracer calibration and ^{238}U decay constant uncertainties (Jaffey et al., 1971). (C) Th/U as a function of $^{206}Pb/^{238}U$ dates for all samples. All uncertainties are given at the 2σ level of confidence.

Figure DR2. Photographs of characteristic bivalves from the Norian-Rhaetian boundary interval. (A) *Oxytoma sp.* cf. *O. inaequivalvis*, left valve, exterior (sample 3a). (B) *Otapiria n. sp.* aff. *O. norica*, left valve, exterior (sample 3'). (C-D) *Monotis subcircularis*.

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Table DR1. U-Pb isotopic data for Upper Norian ash beds from the Pucara basin

	Dates (Ma)								Composition				Isotopic Ratios							
Fraction	$^{206}Pb/^{238}U$ (a)	±2σ abs	$^{206}Pb/^{238}U$ (a,b)	±2σ abs	$^{207}Pb/^{235}U$ (a)	±2σ abs	$^{207}Pb/^{206}Pb$ (a)	±2σ abs	Th/U (d)	Pb* (pg) (e)	Pb_c (pg) (f)	Pb*/Pb_c (g)	$^{206}Pb/^{204}Pb$ (h)	$^{206}Pb/^{238}U$ (i)	±2σ %	$^{207}Pb/^{235}U$ (i)	±2σ %	$^{207}Pb/^{206}Pb$ (i)	±2σ %	Corr. coef.
LP2010-1d																				
z6	205.26	0.19	205.35	0.19	204.5	1.4	195	17	0.57	4.27	0.28	15.27	920	0.0323532	0.10	0.223084	0.8	0.050032	0.7	0.525
z10	205.284	0.080	205.366	0.080	205.5	0.9	208	11	0.90	14.30	0.71	20.09	1111	0.0323572	0.04	0.224280	0.5	0.050294	0.5	0.595
z11	205.292	0.092	205.379	0.092	206.1	0.8	216	10	0.74	8.97	0.42	21.29	1223	0.0323585	0.05	0.225062	0.4	0.050467	0.4	0.487
z5	205.393	0.084	205.483	0.084	205.5	0.8	207	10	0.58	11.86	0.58	20.50	1227	0.0323745	0.04	0.224355	0.4	0.050284	0.4	0.557
z14	205.41	0.15	205.50	0.15	205.3	2.5	203	30	0.62	5.70	0.88	6.47	396	0.0323774	0.08	0.224027	1.4	0.050206	1.3	0.777
z9	205.41	0.13	205.50	0.13	205.5	1.2	207	14	0.70	8.45	0.53	16.08	936	0.0323781	0.07	0.224347	0.6	0.050276	0.6	0.635
z1	205.48	0.12	205.56	0.12	205.7	1.3	208	16	0.71	6.87	0.50	13.74	802	0.0323878	0.06	0.224583	0.7	0.050314	0.7	0.693
z7	205.57	0.13	205.66	0.13	206.4	1.4	216	17	0.64	7.24	0.58	12.57	747	0.0324035	0.06	0.225384	0.8	0.050469	0.7	0.678
z8	205.62	0.17	205.71	0.17	204.5	2.4	192	29	0.64	4.01	0.54	7.47	452	0.0324110	0.09	0.223108	1.3	0.049948	1.2	0.727
z4	205.657	0.090	205.740	0.090	205.9	0.9	209	11	0.87	11.99	0.57	20.97	1167	0.0324169	0.04	0.224858	0.5	0.050330	0.5	0.676
z2	205.66	0.24	205.74	0.24	208.2	3.1	237	36	0.73	3.76	0.61	6.20	370	0.0324167	0.12	0.227609	1.7	0.050947	1.6	0.680
z12	205.709	0.092	205.792	0.092	205.8	0.9	207	10	0.85	8.04	0.36	22.28	1244	0.0324252	0.05	0.224730	0.5	0.050289	0.4	0.652
z13	206.09	0.19	206.18	0.19	206.4	2.5	210	30	0.76	2.84	0.39	7.34	430	0.0324865	0.09	0.225383	1.4	0.050340	1.3	0.701
z3	206.16	0.20	206.25	0.20	205.3	1.6	196	18	0.59	6.59	0.56	11.72	704	0.0324973	0.10	0.224089	0.8	0.050034	0.8	0.585
LP2010-1b																				
z3	205.307	0.094	205.389	0.095	205.7	0.9	210	11	0.90	10.11	0.48	21.01	1161	0.0323609	0.05	0.224552	0.5	0.050349	0.5	0.429
z5	205.483	0.095	205.565	0.096	205.7	0.6	208	7	0.91	20.91	0.51	40.71	2230	0.0323891	0.05	0.224538	0.3	0.050302	0.3	0.608
z4	205.55	0.13	205.63	0.13	205.0	1.5	199	18	0.89	5.27	0.42	12.62	707	0.0323996	0.07	0.223717	0.8	0.050102	0.8	0.519
z14	205.59	0.10	205.68	0.10	205.3	1.1	201	13	0.63	9.14	0.55	16.52	980	0.0324068	0.05	0.224028	0.6	0.050160	0.6	0.423
z6	205.95	0.59	206.03	0.59	204.9	9.4	193	113	0.88	0.98	0.44	2.20	139	0.0324640	0.29	0.223599	5.1	0.049976	4.8	0.826
z15	206.03	0.21	206.11	0.21	205.9	2.7	205	32	0.95	3.29	0.45	7.35	414	0.0324765	0.10	0.224863	1.4	0.050239	1.4	0.664
z8	206.11	0.13	206.19	0.13	206.6	1.3	212	16	0.98	6.86	0.41	16.66	908	0.0324900	0.07	0.225677	0.7	0.050400	0.7	0.563
z12	206.17	0.29	206.25	0.29	206.5	3.7	211	44	0.81	2.69	0.54	4.95	293	0.0324987	0.14	0.225578	2.0	0.050364	1.9	0.607
z11	206.53	0.20	206.62	0.20	207.6	2.4	220	28	0.58	4.20	0.54	7.71	473	0.0325571	0.10	0.226850	1.3	0.050558	1.2	0.730
z9	207.01	0.23	207.09	0.23	206.2	2.2	197	26	0.92	3.68	0.37	9.98	559	0.0326337	0.11	0.225211	1.2	0.050075	1.1	0.492
z1	207.041	0.099	207.131	0.099	206.4	0.9	199	11	0.60	8.30	0.43	19.48	1162	0.0326385	0.05	0.225358	0.5	0.050100	0.5	0.540
z10	207.04	0.13	207.13	0.13	205.7	1.8	191	21	0.55	4.89	0.50	9.76	598	0.0326387	0.07	0.224611	1.0	0.049934	0.9	0.662
z7	207.38	0.23	207.47	0.23	208.9	3.9	227	45	0.62	2.97	0.67	4.44	277	0.0326923	0.11	0.228475	2.0	0.050709	2.0	0.783
z13	207.50	0.33	207.58	0.33	208.1	5.3	215	63	0.89	1.77	0.50	3.54	211	0.0327118	0.16	0.227487	2.8	0.050460	2.7	0.784

(Table DR1 continued)

LP2010-3a																				
z1	204.23	0.13	204.31	0.13	203.7	1.2	197	14	0.69	11.43	0.78	14.74	864	0.0321879	0.06	0.222129	0.6	0.050073	0.6	0.587
z10	205.62	0.15	205.70	0.15	206.9	1.2	221	13	0.62	5.98	0.37	16.26	966	0.0324102	0.07	0.225970	0.6	0.050590	0.6	0.662
z3	205.673	0.088	205.763	0.088	205.7	0.9	206	11	0.61	10.09	0.52	19.46	1158	0.0324195	0.04	0.224520	0.5	0.050251	0.5	0.662
z11	205.68	0.22	205.77	0.22	207.0	2.6	222	30	0.65	3.89	0.50	7.83	469	0.0324201	0.11	0.226095	1.4	0.050602	1.3	0.649
z5	205.69	0.18	205.78	0.18	206.0	1.6	209	18	0.67	4.15	0.33	12.68	748	0.0324228	0.09	0.224904	0.8	0.050332	0.8	0.646
z4	205.74	0.20	205.83	0.20	206.7	2.3	218	28	0.70	3.40	0.45	7.51	447	0.0324301	0.10	0.225824	1.3	0.050526	1.2	0.627
z6	205.76	0.19	205.84	0.19	204.5	1.7	190	20	0.75	4.21	0.36	11.70	676	0.0324328	0.09	0.223095	0.9	0.049911	0.9	0.518
z8	205.77	0.17	205.86	0.17	206.2	2.2	211	27	0.69	3.11	0.39	7.95	473	0.0324356	0.09	0.225137	1.2	0.050364	1.1	0.682
z7	205.88	0.18	205.97	0.18	206.4	2.2	212	26	0.94	2.93	0.33	8.89	497	0.0324534	0.09	0.225364	1.2	0.050387	1.1	0.739
z14	205.93	0.12	206.02	0.12	206.2	1.0	209	11	0.85	5.87	0.28	20.89	1168	0.0324611	0.06	0.225140	0.5	0.050325	0.5	0.560
z13	206.13	0.16	206.21	0.16	205.9	1.2	203	14	0.93	6.49	0.34	19.10	1045	0.0324920	0.08	0.224766	0.7	0.050194	0.6	0.675
z9	206.61	0.19	206.70	0.19	206.9	1.4	210	16	0.59	5.02	0.32	15.63	937	0.0325700	0.10	0.226009	0.7	0.050350	0.7	0.470
z15	206.98	0.21	207.07	0.21	208.0	2.6	219	30	0.58	2.47	0.35	7.06	434	0.0326289	0.10	0.227291	1.4	0.050545	1.3	0.685
z12	477.51	1.16	477.60	1.16	524.1	5.5	733	27	0.45	2.36	0.36	6.58	416	0.0768860	0.25	0.675548	1.3	0.063753	1.3	0.431
z2	585.34	0.33	585.43	0.33	734.6	0.9	1222	3	0.29	14.58	0.35	41.67	2605	0.0950503	0.06	1.061663	0.2	0.081045	0.1	0.540

(a) Isotopic dates calculated using the decay constants $\lambda_{238} = 1.55125E^{-10}$ and $\lambda_{235} = 9.8485E^{-10}$ (Jaffey et al., 1971).

(b) Corrected for initial Th/U disequilibrium using radiogenic ^{208}Pb and $Th/U_{[magma]} = 4 \pm 1$.

(c) % discordance = 100 - (100 * (^{206}Pb/^{238}U date) / (^{207}Pb/^{206}Pb date))

(d) Th contents calculated from radiogenic ^{208}Pb and the ^{207}Pb/^{206}Pb date of the sample, assuming concordance between U-Th and Pb systems.

(e) Total mass of radiogenic Pb.

(f) Total mass of common Pb.

(g) Ratio of radiogenic Pb (including ^{208}Pb) to common Pb.

(h) Measured ratio corrected for fractionation and spike contribution only.

(i) Measured ratios corrected for fractionation, tracer and blank. The composition of the laboratory blank was determined by measuring total procedural blanks spiked with either of the two EARTHTIME tracer solutions. 27 TPBs were measured during the course of this study yielding an average composition of ^{206}Pb/^{204}Pb = 18.469 ± 0.229; ^{207}Pb/^{204}Pb = 15.471 ± 0.160; ^{208}Pb/^{204}Pb = 38.011 ± 0.484 (uncertainties are given as 1 S.D.).

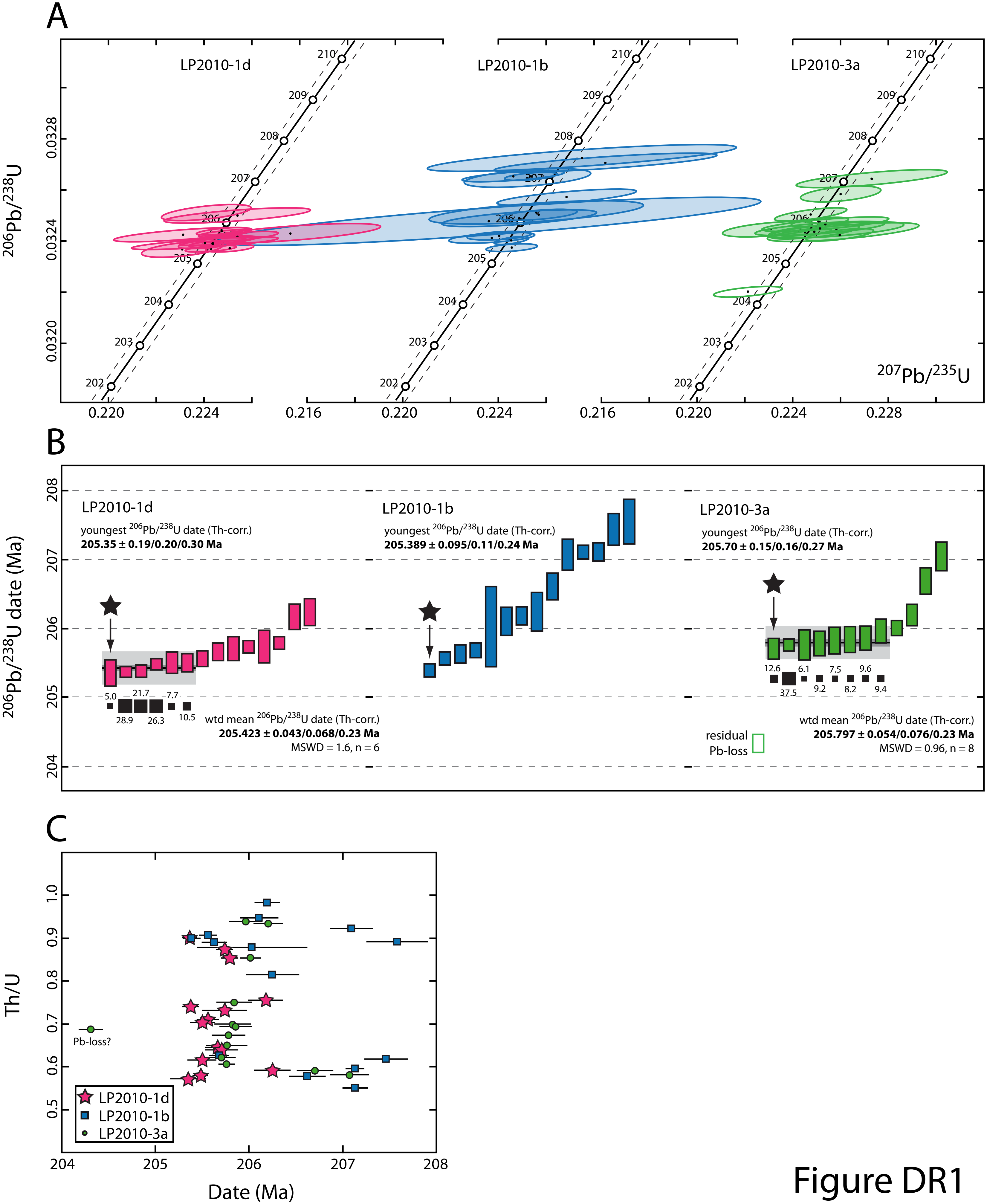
A
LP2010-1d
LP2010-1b
LP2010-3a
206Pb/238U
207Pb/235U
B
206Pb/238U date (Ma)
LP2010-1d
youngest 206Pb/238U date (Th-corr.)
205.35 ± 0.19/0.20/0.30 Ma
wtd mean 206Pb/238U date (Th-corr.)
205.423 ± 0.043/0.068/0.23 Ma
MSWD = 1.6, n = 6
LP2010-1b
youngest 206Pb/238U date (Th-corr.)
205.389 ± 0.095/0.11/0.24 Ma
LP2010-3a
youngest 206Pb/238U date (Th-corr.)
205.70 ± 0.15/0.16/0.27 Ma
wtd mean 206Pb/238U date (Th-corr.)
205.797 ± 0.054/0.076/0.23 Ma
MSWD = 0.96, n = 8
residual Pb-loss
C
Th/U
Date (Ma)
Pb-loss?
LP2010-1d
LP2010-1b
LP2010-3a

Figure DR1

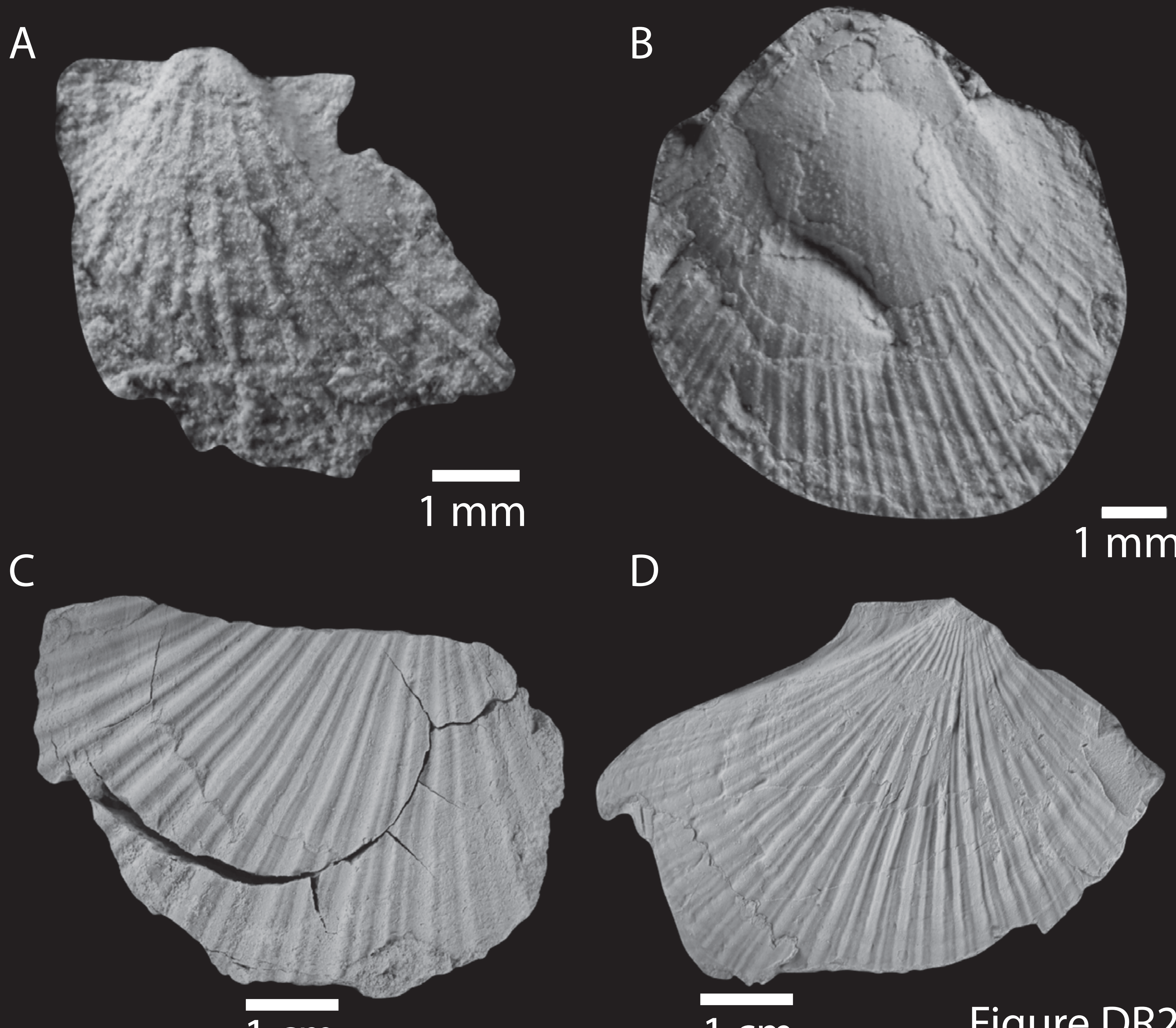

Figure DR2