Supplementary information for

A MIDDLE PERMIAN (ROADIAN) LUNGFISH AESTIVATION BURROW FROM THE RIO DO RASTO FORMATION (PARANÁ BASIN, BRAZIL) AND ASSOCIATED U-Pb DATING

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This file contains supplementary text, tables and figure in order to improve the discussion of the main text.

Comments on the Sample MGS1

Zircons of the sample MGS1 are all inherited having ages in the range of 357–1838 Ma (Supp. Fig. 2). Only eleven ages were obtained because the main aim of this investigation was to determine the age of the mudstone containing pyroclastic material. Eleven analyses are not enough for a consistent interpretation of the sources of the detrital zircons. However, some conclusions are evident. The zircon having a Mesoproterozoic age of 1433 Ma is correlated to the Sunsás orogeny, which is located to the west of the Amazon and La Plata cratons (Pertille et al., 2017), whereas the Paleoproterozoic zircon of 1,838 Ma is comparable to the age of the Juruena orogen of the south Amazon Craton. Three Ediacaran zircons are Brasilian (629, 621, and 554 Ma) in age and certainly derived from rocks of the Brasilian orogen of south Brazil and Uruguay. Two Cambrian zircons (527 and 512 Ma) may be derived from the Pampean orogen in eastern Argentina. Three zircons of 490, 481, and 474 Ma are interpreted as derived from rocks formed during the Famatinian orogeny in Argentina. The youngest grain of 357 Ma (Achalian) is also interpreted as derived from rocks present to the west in Argentina.

Since the mineral concentrate also has rutile, several grains of this mineral were mounted together with zircon to be tested. Rutile, in contrast to detrital zircons present in this sample, could be magmatic (volcanic) and therefore useful to establish the age of the tonstein. Rutile is not very common in non hydrothermalized felsic volcanic rocks (Meinhold, 2010) and usually is very poor in U making its dating difficult. Two grains were dated using $^{207}Pb/^{206}Pb$ ratios. They are very poor in U (estimated at 5–10 ppm) and also poor in common lead. Their $^{207}Pb/^{206}Pb$ ratios are around 0.138 indicating an age of about 2200 Ma, suggesting a comparison to Early Rhyacian rocks such as the Encantadas Complex of south Brazil.

SUPPLEMENTARY TABLE 1–Vertebrate body and trace fossil record of the Rio do Rasto Formation (Serrinha and Morro Pelado members).

BODY FOSSIL RECORD

	VERTEBRATE RECORD	OUTCROP	REGION	LITHOLOGY	REFERENCE
Chondrichthyes	Chondrichthyes indet.	Santo Antônio Farm	Aceguá, RS	Morro Pelado Member	Cisneros and Dentzien-Dias, 2008
	Xenacanthiformes indet.	Barro Alto	São Gabriel, RS	Morro Pelado Member	Pauliv et al., 2016
	Xenacanthus ragonhai	BR-153, Km 20	Jacarezinho, PR	Serrinha Member	Pauliv et al., 2014
	Xenacanthus santosi	BR-153, Km 158[1]	Aceguá, RS	Morro Pelado Member[1]	Würdig-Maciel, 1975
	Triodus richterae	Barro Alto	São Gabriel, RS	Morro Pelado Member	Pauliv et al., 2017
	Sphenacanthus riorastoensis	BR-153, Km 20	Jacarezinho, PR	Serrinha Member	Pauliv et al., 2012
	Hybodontiformes indet.	Posto Queimado	São Gabriel, RS	Morro Pelado Member	Richter and Langer, 1998
		EFCP railway[2]	Ortigueira, PR	Morro Pelado Member	Laurini, 2010
		Barro Alto	São Gabriel, RS	Morro Pelado Member	Henkin et al., 2016
	Hybodontoidea indet.	Posto Queimado	São Gabriel, RS	Morro Pelado Member	Malabarba et al., 2003
Actinopterygii	Palaeonisciformes indet.	BR-153, Km 158[1]	Aceguá, RS	Morro Pelado Member[1]	Würdig-Maciel, 1975
		Posto Queimado	São Gabriel, RS	Morro Pelado Member	Richter and Langer, 1998
		Barro Alto	São Gabriel, RS	Morro Pelado Member	Henkin et al., 2016
		PR-090	São Jerônimo da Serra, PR	Morro Pelado Member	Silva et al., 2012
	Paranaichthyes longianalis	BR-153, Km 42	Santo Antônio da Platina, PR	Serrinha Member	Dias, 2012
	Rubidus pascoalensis	São Pascoal brook	São Pascoal, SC	?	Richter, 2002
	Species A	BR-153, Km 42	Santo Antônio da Platina, PR	Serrinha Member	Vega-Dias et al., 2000
	Species B	BR-153, Km 42	Santo Antônio da Platina, PR	Serrinha Member	Vega-Dias et al., 2000
	Species C	BR-153, Km 42	Santo Antônio da Platina, PR	Serrinha Member	Vega-Dias et al., 2000
Sarcopterygii	Dipnoi indet.	BR-153, Km 42	Santo Antônio da Platina, PR	Serrinha Member	Ragonha, 1989
		Unnamed outcrop	Aceguá, RS	Morro Pelado Member	Figueiredo et al., 2009
		Unnamed outcrop	Hulha Negra, RS	Morro Pelado Member	
	?Gnathorhizidae	Posto Queimado	São Gabriel, RS	Morro Pelado Member	Richter and Langer, 1998
	Acnistia indet.	Serra do Espigão	Monte Castelo and Santa Cecília, SC	Morro Pelado Member	Figueroa et al., 2016

SUPPLEMENTARY TABLE 1–Cont.

BODY FOSSIL RECORD					
	VERTEBRATE RECORD	OUTCROP	REGION	LITHOLOGY	REFERENCE
Temnospondyli	Temnospondyli indet.	PR-090	São Jerônimo da Serra, PR	Morro Pelado Member	Ramos and Vega, 2011; Silva et al., 2012
		Unnamed outcrop	Cândido de Abreu, PR	Morro Pelado Member	Pereira, 2013
		Unnamed outcrop	Otacílio Costa, SC	?	Signorelli, 2005
		Posto Queimado	São Gabriel, RS	Morro Pelado Member	Malabarba et al., 2003
		Barro Alto	São Gabriel, RS	Morro Pelado Member	Strapasson et al., 2015a
	Rhinesuchus-like	EFCP railway[3]	Ortigueira, PR	Morro Pelado Member	Barberena et al., 1980 Barberena and Dias, 1998
	Australerpeton cosgriffi	EFCP railway[4]	Ortigueira, PR	Morro Pelado Member	Barberena, 1998
		PR-090	São Jerônimo da Serra, PR	Morro Pelado Member	Silva et al., 2012; Azevedo et al., 2017
		Monjolo	Mauá da Serra, PR	Morro Pelado Member	Eltink and Langer, 2014
	Bageherpeton longignathus	BR-153, Km 158[1]	Aceguá, RS	Morro Pelado Member[1]	Dias and Barberena, 2001
	Parapytanga catarinensis	Serra do Espigão	Monte Castelo and Santa Cecília, SC	Morro Pelado Member	Strapasson et al., 2015b
	Konzhukovia sangabrielensis	Boqueirão Farm	São Gabriel, RS	Morro Pelado Member	Pacheco et al., 2017
Pareiasauria	*Provelosaurus americanus*	BR-153, Km 204	Aceguá, RS	Morro Pelado Member	Araújo, 1985
		Santo Antônio Farm	Aceguá, RS	Morro Pelado Member	Cisneros & Dentzien-Dias, 2010
		Posto Queimado	São Gabriel, RS	Morro Pelado Member	Malabarba, et al., 2003; Cisneros et al., 2005
Diapsida	Archosauromorpha indet.	Barro Alto	São Gabriel, RS	Morro Pelado Member	Martinelli et al., 2017
Dinocephalia	Dinocephalia indet.	Posto Queimado	São Gabriel, RS	Morro Pelado Member	Langer, 2000
	Titanosuchidae indet.	Posto Queimado	São Gabriel, RS	Morro Pelado Member	Langer, 2000
	Anteosauroidea indet.	Posto Queimado	São Gabriel, RS	Morro Pelado Member	Langer, 2000
	Brithopodinae indet.	Posto Queimado	São Gabriel, RS	Morro Pelado Member	Langer, 2000
	Tapinocephalidae indet.	EFCP railway[5]	Ortigueira, PR	Morro Pelado Member	Boos et al., 2015
	Pampaphonaeus biccai	Boqueirão Farm	São Gabriel, RS	Morro Pelado Member	Cisneros et al., 2012
Anomodontia	*Tiarajudens eccentricus*	Barro Alto	São Gabriel, RS	Morro Pelado Member	Cisneros et al., 2011
	Endothiodon sp.	EFCP railway[6]	Ortigueira, PR	Morro Pelado Member	Barberena et al., 1980
	Rastodon procurvidens	Boqueirão Farm	São Gabriel, RS	Morro Pelado Member	Boos et al., 2016

SUPPLEMENTARY TABLE 1–Cont.

TRACE FOSSIL RECORD					
	VERTEBRATE RECORD	OUTCROP	REGION	LITHOLOGY	REFERENCE
Tracks	Swimming traces	BR-153, Km 20	Jacarezinho, PR	Serrinha Member[7]	Leonardi, 1987
		Coproland	São Gabriel, RS	Morro Pelado Member	Francischini et al., 2015
	Procolophonichnium isp.	PR-090	São Jerônimo da Serra, PR	Morro Pelado Member	Leonardi et al., 2002; Silva et al., 2012
	Rhynchosauroides gangresci	PR-090	São Jerônimo da Serra, PR	Morro Pelado Member	Leonardi et al., 2002; Silva et al., 2012
	Dicynodontipus penugnu	PR-090	São Jerônimo da Serra, PR	Morro Pelado Member	Leonardi et al., 2002; Silva et al., 2012
Coprolites	Morphotype indet.	PR-090	São Jerônimo da Serra, PR	Morro Pelado Member	Silva et al., 2012
	Heteropolar morphotype	Coproland	São Gabriel, RS	Morro Pelado Member	Dentzien-Dias et al., 2012
		Santo Antônio Farm	Aceguá, RS	Morro Pelado Member	Cisneros and Dentzien-Dias, 2008
	Heteropolar edge morphotype	Coproland	São Gabriel, RS	Morro Pelado Member	Dentzien-Dias et al., 2012
	Knot morphotype	Coproland	São Gabriel, RS	Morro Pelado Member	Dentzien-Dias et al., 2012
	Amphipolar morphotype	Coproland	São Gabriel, RS	Morro Pelado Member	Dentzien-Dias et al., 2012
Burrow	Lungfish aestivation burrow	BR-153, Km 659.5	Aceguá, RS	Serrinha Member	This paper

Notes: [1]See discussion about the stratigraphy and age of this outcrop in the main text. [2]South entrance of an unknown tunnel (Km 500.2). Locality informally known as "Tubarão". [3]Unknown entrance of tunnel 12. [4]Specific locality unknown. [5]South entrance of the tunnel 1V. [6]South entrance of the tunnel 22. [7]Although not explicitly mentioned, we infer that this record comes from the Serrinha Member due to the lithological description provided by the author.

SUPPLEMENTARY TABLE 2–U-Pb SHRIMP data of the tonstein from the Serrinha Member deposits of Aceguá (Rio Grande do Sul, southern Brazil).

Spot	U ppm	Th ppm	$^{232}Th/^{238}U$	$^{206}Pb^*$ ppm	comm ^{206}Pb %	$^{238}U/^{206}Pb^*$	error %	$^{207}Pb/^{206}Pb^*$	error %	$^{207}Pb/^{235}U^*$	error %	$^{206}Pb/^{238}U^*$	error %	error corr. ρ (rho)	$^{206}Pb/^{238}U$ age	error 1ρ	$^{207}Pb/^{206}Pb$ age	error 1ρ	Disc. %
MGS1																			
a.1-1	176	58	0.34	15.3	-0.07	9.8927	1.18	0.06366	3.54	0.8873	3.73	0.1011	1.18	0.316	**620.8**	**7.0**	730	75	+16
a.2-1	177	120	0.70	48.3	0.13	3.1468	1.09	0.11237	0.83	4.9237	1.37	0.3178	1.09	0.795	1779.5	16.2	**1838**	**15**	+4
a.2-2	535	335	0.65	35.6	0.00	12.9146	0.85	0.05720	1.12	0.6106	1.41	0.0774	0.85	0.604	**480.8**	**3.9**	499	25	+4
a.3-1	264	29	0.11	17.3	0.16	13.1200	1.59	0.05482	2.00	0.5761	2.55	0.0762	1.59	0.623	**473.5**	**7.3**	405	45	-18
a.3-2	370	149	0.42	28.5	0.13	11.1603	0.87	0.05934	1.58	0.7332	1.81	0.0896	0.87	0.484	**553.2**	**4.6**	580	34	+5
a.4-1	169	125	0.76	33.5	0.00	4.3340	1.20	0.09033	1.06	2.8738	1.60	0.2307	1.20	0.748	1359.4	14.8	**1433**	**20**	+7
a.4-2	149	153	1.06	13.0	0.29	9.8452	1.30	0.06001	3.24	0.8404	3.49	0.1016	1.30	0.372	**623.6**	**7.7**	604	70	-3
a.4-3	334	295	0.91	22.8	0.00	12.6171	0.97	0.05853	3.03	0.6397	3.18	0.0793	0.97	0.306	**491.7**	**4.6**	550	66	+11
a.5-1	119	169	1.46	8.7	0.00	11.7312	1.39	0.06014	2.21	0.7068	2.61	0.0852	1.39	0.532	**527.3**	**7.0**	608	48	+14
a.6-1	296	144	0.50	14.5	0.22	17.5824	1.00	0.06186	2.35	0.4851	2.55	0.0569	1.00	0.392	**356.6**	**3.5**	669	50	+48
a.8-1	97	48	0.52	6.9	0.32	12.0864	1.78	0.05534	4.30	0.6313	4.65	0.0827	1.78	0.382	**512.4**	**8.7**	426	96	-21
MGS2																			
b.1-1	341	235	0.71	12.4	0.00	23.6040	0.91	0.05192	2.19	0.3033	2.37	0.0424	0.91	0.381	**267.5**	**2.4**	282	50	+5
b.1-2	413	264	0.66	15.3	0.65	23.1306	1.59	0.04726	4.86	0.2817	5.11	0.0432	1.59	0.310	**272.8**	**4.2**	62.6	116	-343
b.1-3	536	338	0.65	19.8	0.17	23.2709	0.81	0.05042	2.39	0.2987	2.53	0.0430	0.81	0.322	**271.2**	**2.2**	214	55	-27
b.1-4	361	130	0.37	14.6	0.53	21.1718	4.26	0.05208	4.10	0.3391	5.91	0.0472	4.26	0.720	**291.04**	**5.44**	289	94	-3
b.1-5	502	395	0.81	18.2	0.00	23.6266	0.82	0.05329	1.82	0.3110	1.99	0.0423	0.82	0.410	**267.2**	**2.1**	341	41	+22
b.1-6	436	230	0.55	15.8	0.46	23.6170	0.85	0.04865	3.32	0.2840	3.43	0.0423	0.85	0.249	**267.3**	**2.2**	131	78	-106
b.2-1	457	246	0.55	16.8	0.26	23.3255	0.83	0.05237	2.53	0.3096	2.67	0.0429	0.83	0.313	**270.6**	**2.2**	301	58	+10
b.2-2	304	114	0.39	129.3	0.01	2.0196	2.28	0.17375	1.44	11.8624	2.70	0.4951	2.28	0.845	2592.9	48.7	**2594**	**24**	+0
b.3-1	360	244	0.70	13.3	0.16	23.2446	0.89	0.04771	4.31	0.2830	4.40	0.0430	0.89	0.203	**271.5**	**2.4**	85.0	102	-224
b.3-2	500	430	0.89	18.3	0.22	23.4261	1.34	0.04956	2.60	0.2917	2.92	0.0427	1.34	0.457	**269.5**	**3.5**	175	61	-56
b.3-3	299	133	0.46	11.0	0.00	23.2262	0.89	0.05282	2.13	0.3136	2.31	0.0431	0.89	0.386	**271.7**	**2.4**	321	48	+16
b.4-1	474	279	0.61	17.6	0.28	23.1717	0.82	0.04809	2.83	0.2861	2.94	0.0432	0.82	0.280	**272.4**	**2.2**	104	67	-167
b.4-2	851	603	0.73	31.1	0.31	23.5402	0.93	0.05079	3.14	0.2975	3.27	0.0425	0.93	0.284	**268.2**	**2.4**	231	72	-16
b4-3	426	403	0.98	15.4	0.62	23.8003	0.87	0.04841	4.09	0.2805	4.18	0.0420	0.87	0.208	**265.3**	**2.3**	119	96	-125
b.5-1	431	210	0.50	16.0	0.06	23.1294	0.83	0.05016	2.13	0.2990	2.29	0.0432	0.83	0.362	**272.9**	**2.2**	203	49	-35
b.5-2	772	545	0.73	28.7	0.00	23.1307	0.78	0.05267	1.53	0.3140	1.72	0.0432	0.78	0.454	**272.8**	**2.1**	315	35	+14
b.5-3	440	241	0.57	15.7	0.00	24.0272	0.84	0.05450	1.85	0.3127	2.03	0.0416	0.84	0.411	**262.9**	**2.2**	392	42	+34

Notes: (*) ratios are radiogenic component, all corrected for common lead; common ^{206}Pb calculated from measured ^{204}Pb; disc. = discordance, as 100 - 100{t[$^{206}Pb/^{238}U$]/t[$^{207}Pb/^{206}Pb$]}; selected ages are in bold face.

SUPPLEMENTARY TABLE 3–Comparison between LGP–H429 and vertebrate burrow ichnotaxa (ordered by age). Asterisks indicate ichnotaxa in which the architect was preserved inside the burrow.

Ichnotaxa	Architecture	Presence of chambers	Presence of branching	Cross-section	Orientation	Surface features	Age and locality	Probable producer	Reference
*Torridorefugium eskridgensis**	Vertical shafts tapering downwards	No	No	Elliptical	Nearly vertical	Irregularly spaced nodes (only in Type II burrows)	Cisuralian of Kansas, USA	Lysorophid amphibians (*Brachydectes*)	Hembree et al., 2005
Reniformichnus katikatii	Subhorizontal, slightly sinuous shaft	No	No	Reniform	Subhorizontal (< 30º)	Scratches subparallel to tangential to the main axis of the burrow	Early Triassic of South Africa and Antarctica	Indeterminate tetrapods (cynodonts, procolophonids, dicynodonts, etc)	Krummeck and Bordy, 2017
Redondarefugium abercrombieorum	Vertical to oblique simple shafts with a flask-shaped terminus	Yes	No	Circular	Vertical to oblique	Wrinkle-like ornamentation	Late Triassic of New Mexico, USA	Lungfishes	Gobetz et al., 2006; Lucas et al., 2010
Ichnogyrus nididensis	Helical	Enlargement of the coils suggests the presence of chambers	No	Unknown	Unknown (specimen found *ex situ*)	No	Early Eocene	Indeterminate mammal	Bown and Kraus, 1983
Daimonelix isp.*	Helical	Yes	No	Nearly circular	25º–30º coils	Incisor and claw traces	Late Oligocene–early Miocene of Nebraska, USA	Beavers (*Palaeocastor*)	Barbour, 1892, 1895; Martin and Bennett, 1977

SUPPLEMENTARY TABLE 3–Cont.

Alezichnos trogodont	Sinuous, rambling or weakly helical	Yes	Yes	Nearly circular	Variable	Paired grooves (incisors) on the ceiling and upper walls and ridges (claws) on the floors and lower walls	early Miocene of Nebraska, USA	Rodents (*Gregorymys*)	Gobetz and Martin, 2006
Alezichnos	Sinuous	Unknown	Occasionally	Slightly	Variable	Sets with two or three	Miocene, of	Rodents	Gobetz,

chelecharatos				ovate		parallel ridges	Colorado, USA	(*Pterogaulus*)	2006
Daimonelix petalichnus	Helical	Yes	No	?	5º–30º coils	No	Miocene of Colorado, USA	Mustelids	Hembree and Hasiotis, 2008
Kladosystemites homocylindrichnus	Boxwork of interconnected horizontal tunnels and short subvertical shafts	No	Yes, Y-shaped	Circular to elliptical	Horizontal and subvertical shafts	No	Miocene of Colorado, USA	Amphisbaenians	Hembree and Hasiotis, 2008
Katarrhedrites athesphatichnus	Subhorizontal tunnels with terminal chamber	Yes	No	?	10º–15º near the surface and 1º–5º near base	No	Miocene of Colorado, USA	Canids or ursids	Hembree and Hasiotis, 2008
Katarrhedrites atyphichnus	Subhorizontal tunnels with terminal chamber	Yes	No	?	40º–50º shafts	No	Miocene of Colorado, USA	Indeterminate reptiles or mammals	Hembree and Hasiotis, 2008

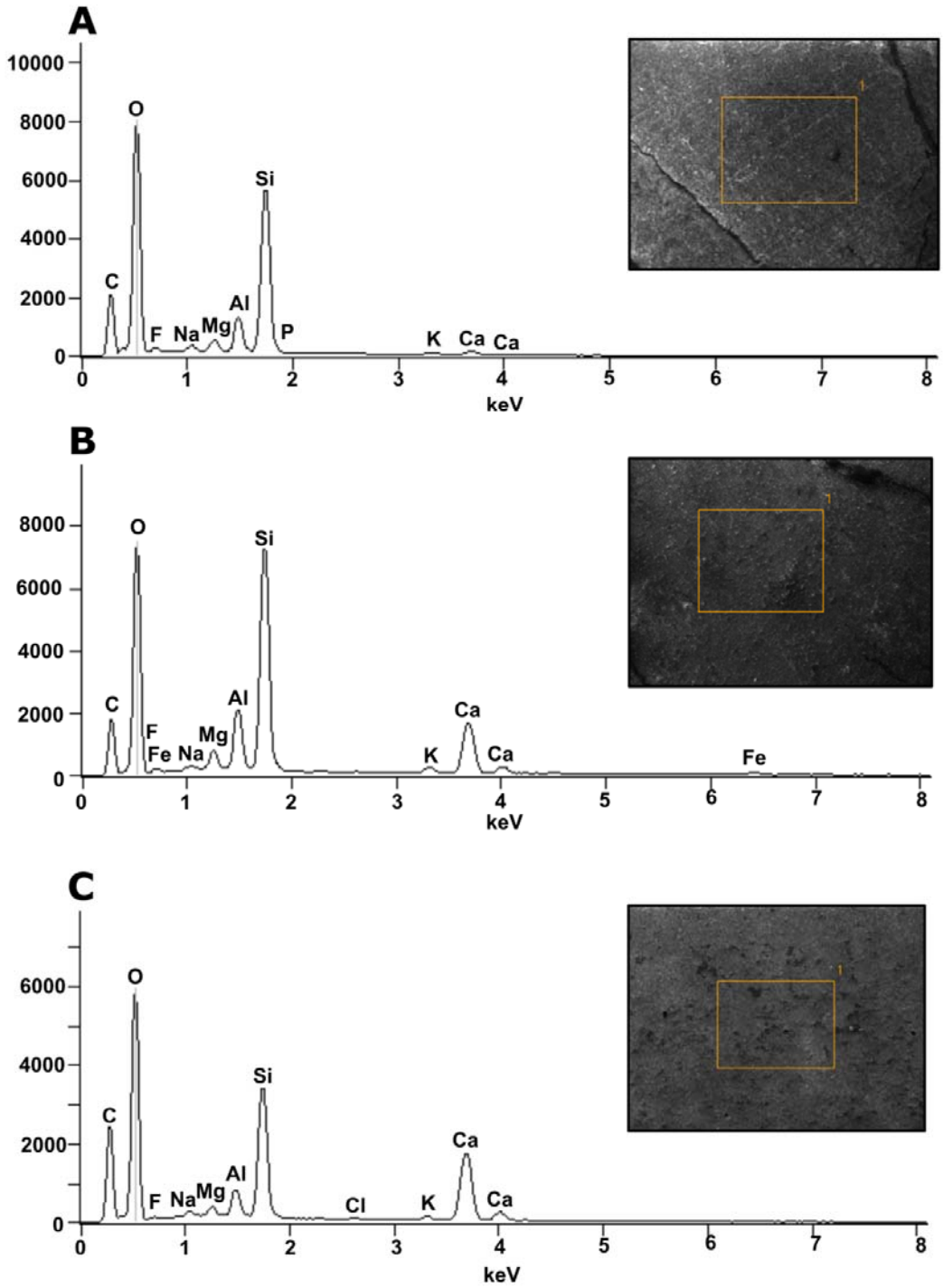
SUPPLEMENTARY TABLE 3–Cont.

Polychoredrites tetrachelichnus	Interconnected system of tunnels	Yes	Yes	Elliptical	10º–20º	Three to four parallel striae (scratch traces)	Miocene of Colorado, USA	Rodents or mustelids	Hembree and Hasiotis, 2008
Nagtuichnus meuleni	Meniscate tunnels	No	No	Nearly circular	Subhorizontal	Parallel ridges. Paired pits on the concave surface of the menisci	Miocene–Holocene of La Pampa and Río Negro, Argentina	Pink fairy armadillos (*Chlamyphorus*)	Melchor et al., 2012

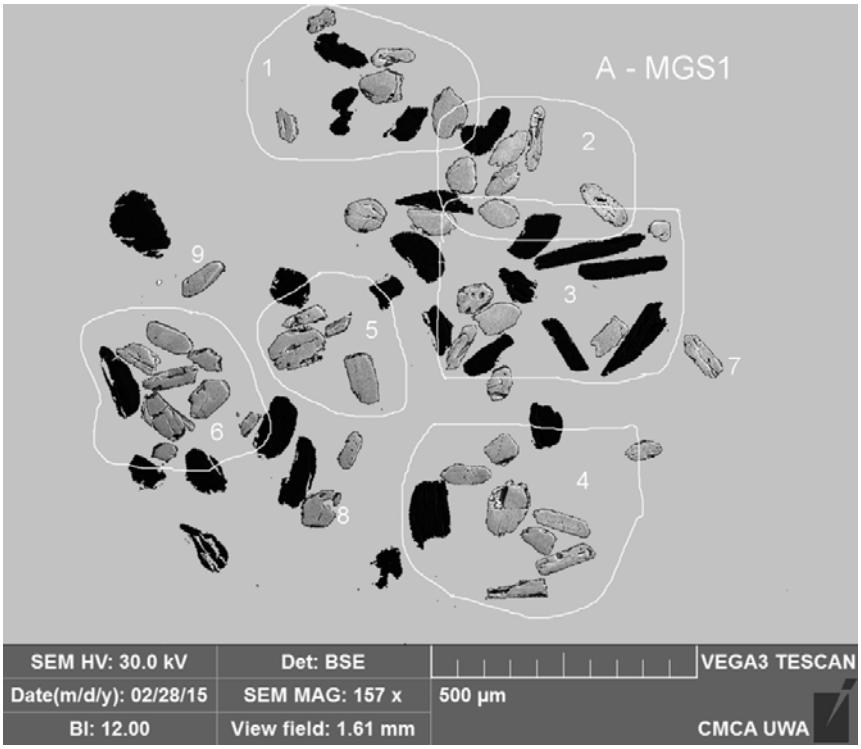
Megaichnus major	Complex system of tunnels and chambers	Yes	Yes	Subcircular to subelliptical	Subhorizontal	Scratches (claw traces) and smooth walls and ceiling	Plio–Pleistocene of South and southeastern Brazil and northwestern Argentina	Ground sloths, giant armadillos or pampatherids	Lopes et al., 2017
Megaichnus minor	Complex system of tunnels and chambers	Yes	Yes	Subcircular to subelliptical	Horizontal to sloped	Grooves (claw traces) and osteoderm marks and impressions	Plio–Pleistocene of South and southeastern Brazil and northwestern Argentina	Ground sloths, giant armadillos or pampatherids	Lopes et al., 2017
LGP–H429 (no ichnotaxon attributed)	Vertical simple shaft	No	No	Circular	32°	No	Early Guadalupian of Southern Brazil	Lungfish	This paper

SUPPLEMENTARY TABLE 4–Semiquantitative proportions (in %) of the main elements of each paleosol level, obtained by Energy-dispersive X-ray spectroscopy (EDS).

	Paleosol Type 1	**Paleosol Type 2**	**Paleosol Type 3**
C	16.31	10.89	13.58
O	55.51	49.56	54.76
Ca	1.15	10.74	14.90
Si	20.08	19.63	12.09
Mg	1.35	1.55	0.83
Al	3.68	4.75	2.32
K	0.56	0.90	0.65
Na	0.86	0.65	0.68
F	0.34	-	-
P	0.16	-	-
Fe	-	1.31	-
Cl	-	-	0.18



SUPPLEMENTARY FIGURE 1–Energy-dispersive X-ray spectroscopy (EDS) profiles of each paleosol level. A) Paleosol Type 1. B) Paleosol Type 2. C) Paleosol Type 3.



SUPPLEMENTARY FIGURE 2– BSE image of the grains of sample MGS1. The light grey grains are zircon whereas the dark grains are rutile.

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