Supplementary Online Material DR2009257

Over a Millennium of Intensive Pb and Hg pollution at Cerro de Pasco, Peru

Colin A. Cooke[*,1], Alexander P. Wolfe[1], and William O. Hobbs[1,2]

[1]Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Alberta, T6G 2E3, Canada

[2]Department of Geosciences, University of Nebraska-Lincoln, Lincoln, Nebraska, 68588-0340, USA

* Corresponding author phone: (780) 492-5451; fax: (780) 492-2030; email: cacooke@ualberta.ca

Table DR1. Measurements of total ^{210}Pb activity, associated CRS dates, and CRS sedimentation rates for the Llamacocha core.

Depth (cm)	^{210}Pb (Bq/g)	1 σ error	CRS date	1 σ error	CRS Sed. Rate (g/m^2/yr)	1 σ error
0-1	1.15	0.06	2007	0	85	8
2-3	1.20	0.04	2006	0	78	6
4-5	1.19	0.04	2003	0	73	5
6-7	1.04	0.03	2000	0	75	5
8-9	1.01	0.03	1995	1	67	5
10-11	0.93	0.03	1990	1	61	6
12-13	0.68	0.03	1981	2	66	6
14-15	0.48	0.02	1974	2	78	7
16-17	0.35	0.02	1967	5	91	12
18-19	0.38	0.02	1961	5	68	10
20-21	0.29	0.02	1950	7	66	12
24-25	0.16	0.01	1929	11	75	14
28-29	0.12	0.01	1914	20	75	21
32-33	0.11	0.01	1894	30	56	26
41-42	0.06	0.01				
51-52	0.05	0.00				

Table DR2. Table of radiocarbon dates used in the core chronology. Note that BC dates are denoted as negative.

UCI	Depth (cm)	Size (mg carbon)	±	fraction Modern	±	^{14}C age (BP)	±	1 σ Calibrated AD/BC
56389	33-36	0.029	1.5	0.946	0.004	445	40	1445-1610
51340	42-45	0.029	0.8	0.916	0.004	705	40	1290-1385
49761	56-59	0.065	4.0	0.865	0.003	1160	30	900-985
56386	61-64	0.033	1.2	0.829	0.004	1510	40	580-645
56387	85-86	0.033	1.4	0.768	0.005	2120	60	-170-5

Table DR3. Table of stable Pb isotopic values for Llamacocha sediment samples.

Depth (cm)	Calibrate year (AD/BC)	$^{206}Pb/^{204}Pb$	1σ	$^{207}Pb/^{204}Pb$	1σ	$^{208}Pb/^{204}Pb$	1σ	$^{208}Pb/^{206}Pb$	1σ	$^{207}Pb/^{206}Pb$	1σ
3	2004	18.774	9.01E-04	15.647	1.07E-03	38.795	3.47E-03	2.066	9.11E-05	0.833	1.92E-05
19	1955	18.781	8.21E-04	15.648	9.64E-04	38.819	3.06E-03	2.067	8.00E-05	0.833	1.56E-05
38	1582	18.814	1.20E-03	15.651	1.23E-03	38.825	3.60E-03	2.064	7.91E-05	0.832	1.88E-05
45	1322	18.816	1.72E-03	15.640	1.73E-03	38.788	5.04E-03	2.061	9.39E-05	0.831	2.16E-05
51	1091	18.852	1.80E-03	15.649	1.72E-03	38.818	4.49E-03	2.059	8.04E-05	0.830	2.41E-05
58	823	18.936	1.98E-03	15.652	2.06E-03	38.818	5.24E-03	2.050	6.88E-05	0.827	2.73E-05
63	643	19.227	9.74E-04	15.668	1.09E-03	38.877	3.27E-03	2.022	9.57E-05	0.815	2.27E-05
69	453	19.457	1.52E-03	15.691	1.25E-03	38.943	3.66E-03	2.002	7.02E-05	0.806	1.65E-05
76	256	19.441	1.78E-03	15.688	1.68E-03	38.932	4.75E-03	2.003	8.82E-05	0.807	1.97E-05
81	125	19.454	1.39E-03	15.663	1.45E-03	38.863	4.26E-03	1.998	9.30E-05	0.805	2.13E-05
96	-255	19.589	9.70E-04	15.698	1.16E-03	38.975	3.57E-03	1.990	8.13E-05	0.801	1.76E-05
101	-350	19.606	2.01E-03	15.689	1.77E-03	38.937	4.85E-03	1.986	7.25E-05	0.800	1.79E-05
NBS 981+ Tl		16.930	1.05E-03	15.485	1.15E-03	36.683	3.36E-03	2.167	8.17E-05	0.915	2.04E-05
NBS 981+ Tl		16.931	1.11E-03	15.484	1.26E-03	36.675	3.09E-03	2.166	6.33E-05	0.914	1.96E-05
NBS 981+ Tl		16.935	9.72E-04	15.488	1.08E-03	36.687	2.86E-03	2.166	6.34E-05	0.915	1.82E-05
Certified value		16.941		15.496		36.722		2.168		0.915	

Table DR4. Table of stable Pb isotopic values for regional ores; source references are as indicated.

Mine	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	$^{208}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$	Reference
Cerro de Pasco	18.778	15.637	38.811	2.067	0.833	Mukasa et al., 1990
	18.778	15.661	38.888	2.071	0.834	
	18.821	15.96	38.954	2.070	0.848	
	18.789	15.658	38.870	2.069	0.833	
Cerro de Pasco	18.776	15.666	38.902	2.072	0.834	Sangster et al., 2000
Atacocha	18.822	15.681	38.968	2.070	0.833	Gunnesch and Baumann, 1984
	18.839	15.693	39.009	2.071	0.833	
	18.793	15.659	38.866	2.068	0.833	
	18.810	15.673	38.937	2.070	0.833	
	18.860	15.727	39.073	2.072	0.834	
Atacocha	18.823	15.682	38.969	2.070	0.833	Gunnesch et al., 1990
	18.839	15.693	39.009	2.071	0.833	
	18.793	15.653	38.863	2.068	0.833	
	18.810	15.673	38.937	2.070	0.833	
	18.860	15.727	39.073	2.072	0.834	
	18.789	15.651	38.866	2.069	0.833	
Milpo	18.801	15.643	38.866	2.067	0.832	Gunnesch and Baumann, 1984
	18.829	15.673	38.938	2.068	0.832	
	18.851	15.701	39.047	2.071	0.833	
	18.848	15.685	38.987	2.068	0.832	
	18.819	15.664	38.91	2.068	0.832	
	18.771	15.667	38.925	2.074	0.835	
	18.835	15.683	38.967	2.069	0.833	
	18.849	15.697	39.04	2.071	0.833	
	18.832	15.678	38.958	2.069	0.833	
	18.842	15.673	38.956	2.068	0.832	
	18.826	15.676	38.959	2.069	0.833	
	18.801	15.649	38.876	2.068	0.832	
	18.819	15.674	38.932	2.069	0.833	
	18.817	15.665	38.926	2.069	0.832	

Figure DR1. Down-core profile of A: total ^{210}Pb activity, B: associated CRS dates, and C: Sedimentation rate for the Llamacocha core.

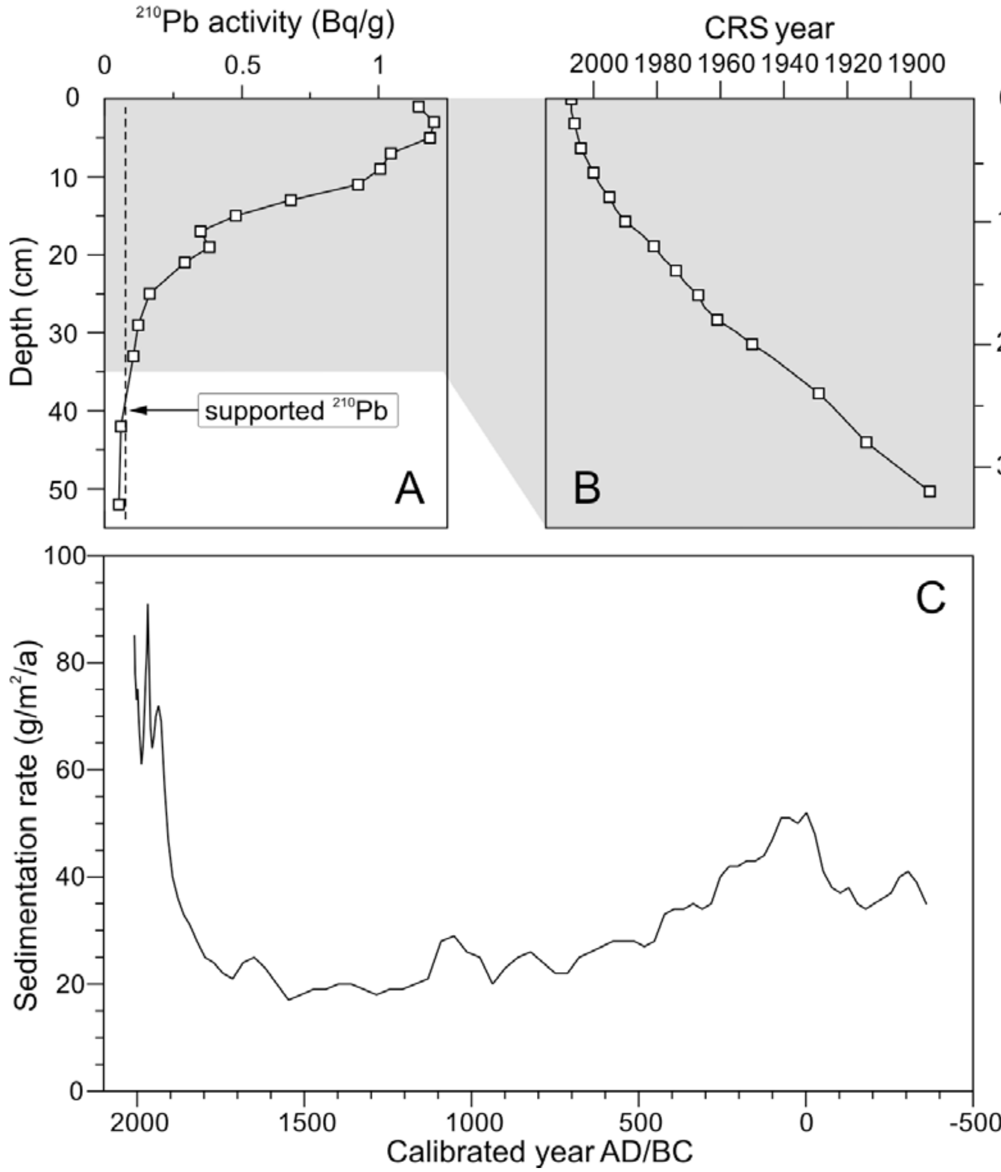


Figure DR2. Elemental fluxes for each of the metals measured. Na, Mg, Al, Ca, Ti, Mn, Fe, Zn, As, Cu, Sr, and Pb are in the units mg $m^{-2}\ yr^{-1}$; Hg, Sb, Cr, and Sc are in the units µg $m^{-2}\ yr^{-1}$. Note Mn, Zn, Hg, As, Pb, and Sb are plotted on a log scale.

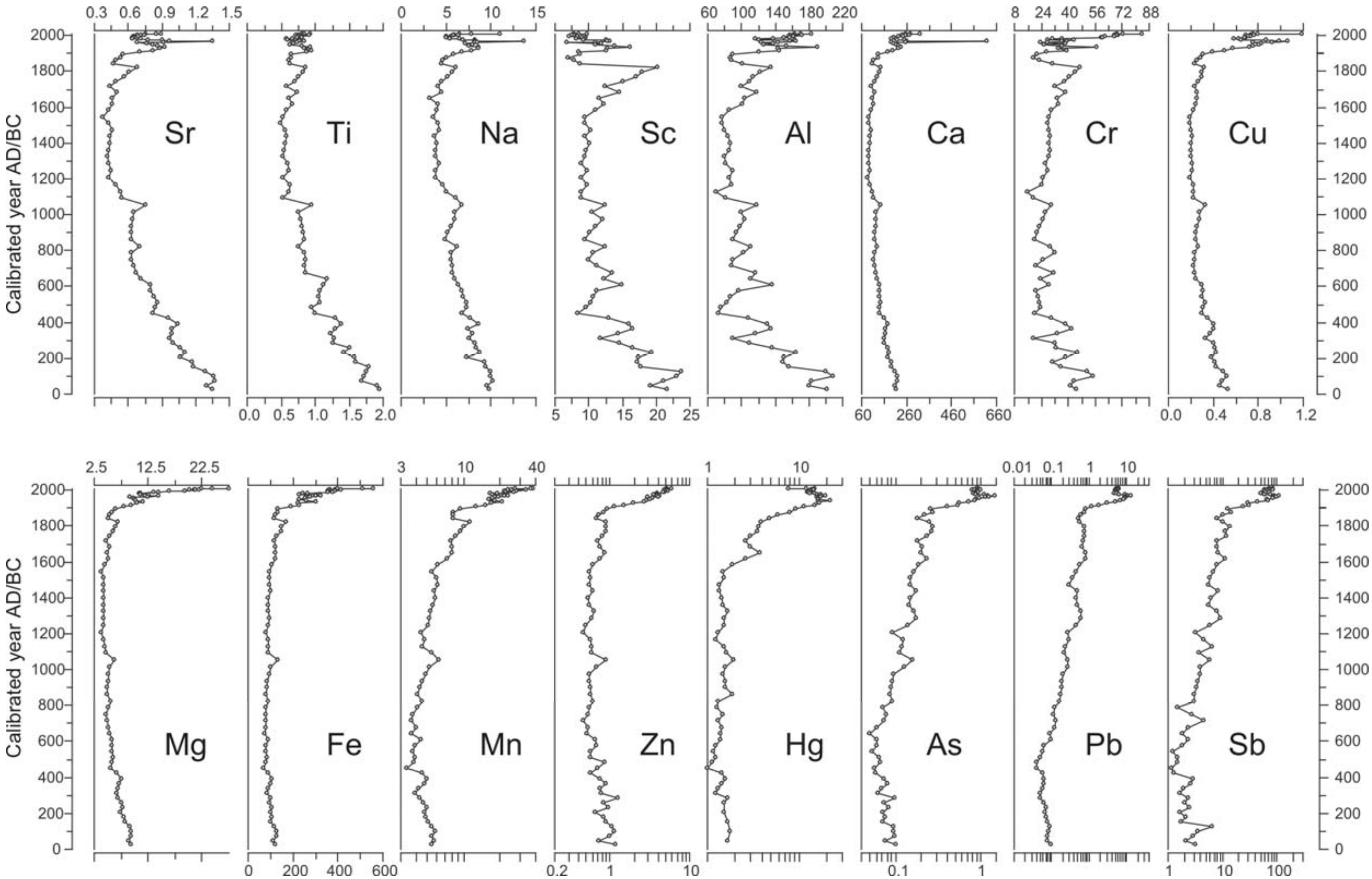


Figure DR3. Plot of $^{206}Pb/^{204}Pb$ vs. A: $^{207}Pb/^{204}Pb$ and B: $^{208}Pb/^{204}Pb$. Stable Pb isotopic ratios for Llamacocha sediment are plotted alongside stable Pb isotopic ratios from galena (PbS) from local mines (Pb data for Llamacocha sediment are provided in Table DR3 and Pb data for ores in Table DR4). The largest and historically the most economically important of these mines is Cerro de Pasco. Milpo, Atacocha, and the St Vicenete mine are all located 10-20 km north of Cerro de Pasco. The cluster of four background samples is those intervals which pre-date ~600 AD, and thus pre-date Pb enrichment associated with the rise of regional metallurgy. Llamacocha sediment Pb ratios roughly plot along a straight line between background and 20th century intervals. The 20th century samples plot directly on top of the low-end of Cerro de Pasco ores (especially $^{208}Pb/^{204}Pb$), indicating Cerro de Pasco is the major source of anthropogenic Pb in Llamacocha sediment, though limited influence by other regional ores cannot be ruled out.

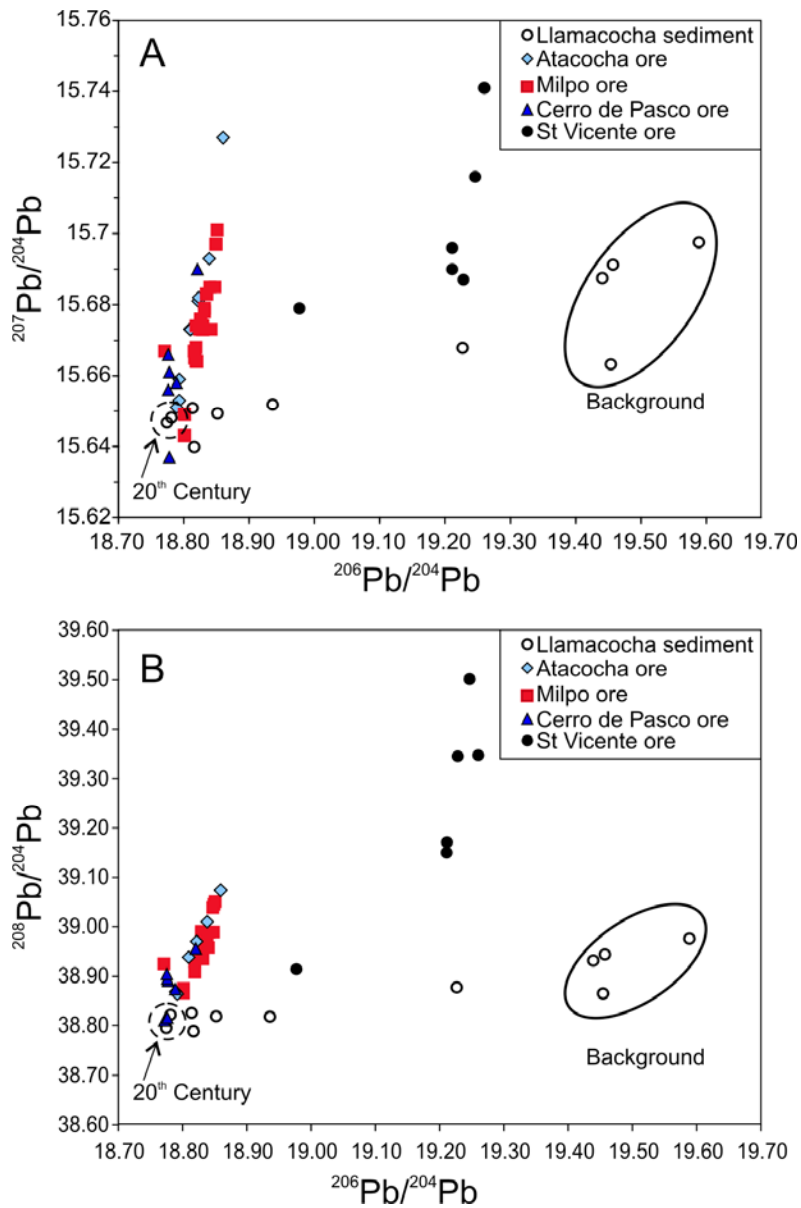
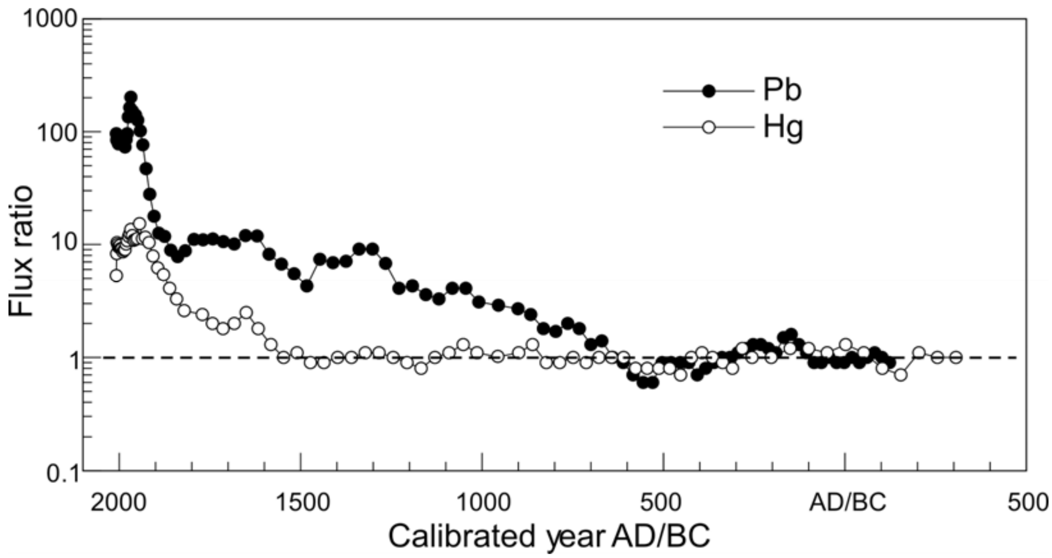


Figure DR4. The down-core flux ratio profile for both Pb and Hg. Flux ratios (sample to average background fluxes) provide a unitless measure of relative increases in metal accumulation rates, and facilitate comparisons between lake records. The average background Pb flux is 0.07 (±0.01) mg m^{-2} yr^{-1} (n=35; pre-600 AD) and the average rate of background Hg flux is 1.5 (±0.2) µg m^{-2} yr^{-1} (n=49; pre-1600 AD).



References:

Gunnesch, K.A., and Baumann A. 1984, The Atacocha district, central Perú: Some metallogenetic aspects, in Wauschkuhn A., Kluth, C., and Zimmermann, R.A., eds., Syngenesis and epigenesis in the formation of mineral deposits Berlin, Heidelberg, New York, Springer-Verlag, p. 448–456.

Gunnesch, K.A., Baumann A., and Gunnesch, M., 1990, Lead isotope variations across the central Peruvian Andes: Economic Geology v. 85, p. 1384–1401, DOI: 10.2113/gsecongeo.85.7.1384

Mukasa, S.B., Vidal, C., C.E., Injoque-Espinoza, J., 1990, Pb Isotope Bearing on the Metallogenesis of Sulfide Ore Deposits in Central and Southern Peru: Economic Geology, v. 85, p. 1438–1436.

Sangster, D.F., Outridge, P.M., and Davis, W.J., 2000, Stable lead isotope characteristics of lead ore deposits of environmental significance: Environmental Reviews, v. 8, p. 115–147, doi: 10.1139/er-8-2-115.