Appendix:
Tables

Table A.1 Properties of Elemental Lead

Atomic Weight	207.2
Atomic Number	82
Valences	2 and 4
Crystal Structure	face-centered cubic
a dimension	4.949 Å
Bond Length, Pb, Pb, at 25° C	3.499Å
Ionization potentials, Ev	7.42, 15.03, 32.08, 42.25, 69.7
Specific Gravity, g/ml	
20° C	11.34
327° C (solid)	11.005
327° C (liquid)	10.686
Specific Heat, cal/g	
0° C	0.0297
20° C	0.0306
327° C	0.0320
Vapor Pressure, mm Hg	
987° C	1.0
1167° C	10.0
1417° C	100.0
Viscosity, cP	
441° C	2.12
551° C	1.70
703° C	1.35
Surface Tension, dyne/cm, 327.4° C	444
Melting Point, °C	327.4
Boiling Point, °C	1751
Electric Resistivity, microohm/cm, 20° C	20.65
Thermal Conductivity, cal/sec/sq cm, 20°C	0.083
Tensile Strength, Kg/sq cm.	126.55-175.77
Modulas of Elasticity, 10^6 Kg/sq cm	0.155
Latent Heat of Vaporization, cal/g	204
Latent Heat of Fusion, cal/g	5.89
Heat of Fusion, cal/atm	1,225
Heat of Vaporization, cal/atm	42,880
Entropy at 25° C, cal/atom deg	15.49
Heat Capacity at 327° C, cal/atom deg	6.80

Table B.1: Minerals Important in the History of Lead

Class		Formula	Structure	Uses
Sulfides				
	Galena	PbS	Cubic	Mined, Egyptian Kohl
	Altaite	PbTe	Cubic	IR Sensors
	Clausthalite	PbSe	Cubic	IR Sensors
Oxides				
	Litharge	αPbO		
	Massicot	βPbO	Orthorhombic	Paint
	Minium	$Pb^{2+}{}_2Pb^{4+}O_4$	Tetragonal	Red paint
		$Pb^{2+}{}_2Sn^{4+}O_4$		Giallino = Lead Tin Yellow I, non-native
	Plattnerite	PbO_2	Tetragonal	Batteries
Pyrochlore		**$A_{1-2}B_2O_6(O,OH,F)\text{-}nH_2O$**		
	Bindheimite	$Pb_2Sb_2O_6(O,OH)$	Cubic	=Naples Yellow
		$PbSn_{1-x}Si_xO_3$		Lead Tin Yellow II, non- native
Carbonates				
	Cerrussite	$PbCO_3$	Orthorhombic	Silverstone, White Paint
Acetates				
		$Pb(CH_3COO)_2$		Sugar of lead: fungicide, sweetner
Sulfates				
	Anglesite	$PbSO_4$	Orthorhombic	Batteries, additive to
	yellow chrome			
	Plumbojarosite	$PbFe^{3+}{}_6(SO_4)_4(OH)_{12}$	Trigonal	Mined
Tungstates, Molybdates and Chromates				
	Crocoite	$PbCrO_4$	Monoclinic	Rare: Yellow chrome
	Wulfenite	$PbMoO_4$	Tetragonal	Additive to yellow chrome
Apatite Group: $Ca_5(PO_4, CO_3)_3(F,Cl,OH)$				
	Pyromorphite	$Pb_5(PO_4)_3Cl$	Hexagonal	Used to stabilize lead in soil

Table B.2: Half Lives of U and Th precursors

Reaction	**Half life (Byr)**	**Decay Constant, λ, yr-1**
$^{238}U \rightarrow {}^{206}Pb$	4.47	1.5512×10^{-10}
$^{235}U \rightarrow {}^{207}Pb$	0.704	1.848×10^{-10}
$^{232}Th \rightarrow {}^{208}Pb$	14.01	0.49475×10^{-10}

Table B.3: Lead Isotopes

(Not shown are man made isotopes with very short (< s) life spans.)
Radioactive Isotopes Shown in Bold

Isotope	Source	Half-life	% Abundance
^{201}Pb	man	>500yr	~0
^{204}Pb	Big Bang	stable	1.36
^{206}Pb	^{238}U	stable	25.4
^{207}Pb	^{235}U	stable	21.1
^{208}Pb	^{232}Th	stable	52.1
^{209}Pb	^{241}Pu	3.32 hr	~0
^{210}Pb	^{238}U	25 yr	~0
^{211}Pb	^{235}U	25 min	~0
^{212}Pb	^{232}Th	10.6 hr	~0
^{214}Pb	^{238}U	26.8 min	~0

Table B.4: Isotope Percents of Major Commercial Lead Ores

	^{204}Pb	**^{206}Pb**	**^{207}Pb**	**^{208}Pb**
Con Mine, Canada	1.549±0.001	21.94±0.03	23.53±0.02	52.97±0.04
Bluebell, Canada	1.39±0.02	24.32±0.07	21.56±0.07	52.73±0.06
Joplin, Missouri.	1.25	26.43	20.00	51.32
Bunker Hill, Idaho	1.438±0.002	23.69±0.02	22.52±0.002	52.34±0.004
San Antonio, Mexico	1.34±0.005	25.26±0.004	21.1196±0.003	52.20±0.05
Broken Hill, Australia	1.46±0.005	23.50±0.005	22.64±0.005	52.34±0.004
Average:	1.40±0.1	24.35±1.86	22.10±1	52.31±0.6
Relative Standard Deviation	7%	7.63%	4.52%	1.1%

Table B.5: Electronic configuration of Pb, Th, U, O, and S.

Specie	Atomic Number	Atom	Atom Radii In pm	Ion	Comment	Ion Radii In pm
Li	4	$[He]2s^1$		Li^+: [He]		
Be	5	$[He]2s^2$		Be^{2+}: [He]		
Oxygen	8	$[He]2s^2 2p^2$	150	O^{2-}: [Ne]	Filled shell	121 -126
Na	12	$[Ne]3s^1$		Na^+ [He]		
Mg	13	$[Ne]3s^2$		Mg^{2+} [He]		
Sulfur	16	$[Ne]3s^2 3p^4$	180	S^{2-}: [Ar]	Filled shell	170
Lead	82	$[Xe]6s^2 4f^{14} 5d^{10} 6p^2$	200	Pb^{2+}: $[Xe]6s^2 4f^{14} 5d^{10}$	Filled d orbital	112 -133
					Filled s orbital	
				Pb^{4+}: $[Xe]4f^{14} 5d^{10}$	Filled d orbital	
Thorium		$[Rn]7s^2 6d^2$		Th^{2+}: $[Rn]7s^2$	Filled s orbital	
				Th^{4+}: [Rn]	Filled shell	108
Uranium		$[Rn]7s^2 5f^3 6d^1$	190	U^{4+}: $[Rn]7s^2$	Filled s orbital	103
				U^{6+}: [Rn]	Filled shell	

Table B.6: Condensation Temperatures

Element	Condensation T (°K)	Major host phase	Host Formula
Re,Os,W	1,800	Metal Alloy	
Zr	1,750	Zircon	ZrO_2
Al	1,680	Corundum (al oxide)	Al_2O_3
		Spinel	$MgAl_2O_2$
Ti	1,590	Perovskite	$CaTiO_3$
Th	1,590	Perovskite	
Ca	1,520	Melilite	
Ir, Ru, Mo	1,600	Metal alloy	
Mg	1,340	Forsterite	Mg_2SiO_4
		Enstatite	$MgSiO_3$
Si	1,311	"	
Ni	1,354	FeNi metal	
Fe	1,336	FeNi metal	
Pd	1,334	FeNi metal	
Cr	~1,300	Forsterite, enstatie, FeNi metal	
		Olivene	$Cr_2^{2+}SiO_4$
		Pyroxene	$Cr^{2+}SiO_3$
P	1,267	Fe_3P	
Li	1,225	Enstatite	
Au	1,225	FeNi metal	
Mn	1,190	Forsterite	
Na	970	Anorthite	$CaAl_2Si_2O_8$
K	1000	Anorthite	
S	648	FeS	
Pb	496	FeS	
Bi	451	FeS	
Tl	428	FeS	

Table B.7: Mineral Stability in Earth Surface

Stage	Mineral	Formula	Density
1	Gypsum, halite	$CaSO_4$	2.32
2	Calcite	$CaCO_3$	2.7
3	Olivine-hornblende	Mg_2SiO_4	3.275
4	biotite	$K(Mg,Fe)_3(Al,Fe)Si_3O_{10}(OH,F)_2$	2.7
5	Albite	$(Ca,Na,Fe)_2(Ta,Nb)_2(O,OH,F)_7$	4.3
6	Quartz	SiO_2	2.65
7	Illite		2.77
8	Hydrous Mica		
9.	Montmorillonite	$(Na,Ca)_{0.33}(Al,Mg)_2Si_4 O_{10}(OH)_2 \cdot nH_2O$	2-3
10	Kaolinite	$Al_2Si_5O_5(OH)_4$	2.6
11	Gibbsite	$Al(OH)_3 \cdot 3H_2O$	2.4
12	Hematite, Goethite	FeO_2	3.3-4.3
13	Rutile, Corundum	TiO_2, αAl_2O_3	4.23

Table B.8: Abundance of Elements

Element	Relative Amt Solar System	Wt % in Crust	Compound	Wt % in Crust	Wt% in Mantle
O	23.8×10^6	46.6			
Si	1.0×10^6	27.7	SiO_2	57.3	45.57
Al	85×10^3	8.13	Al_2O_3	15.9	4.73
Fe	0.9×10^6	5.0	FeO	9.1	8.17
Ca	61×10^3	3.63	CaO	7.4	3.75
Na	57×10^3	2.83			
K	3.8×10^8	2.59			
Mg	1.1×10^6	2.09	MgO	5.3	36.33
Ti	2.4×10^3	0.44			
H	27.9×10^9	0.14			
P	10×10^3	0.10			
Mn	9.6×10^3	0.09			
Ba	4.5	0.04			
Pb	3.2				

Table B.9: Structure of oxyanions (O^{2-} 1.26Å)

Ion	Ionic	Oxyanion	R_c/R_a Range	R_c/R_{oxygen}	C.N.	Predicted Structure
			<0.15		2	Linear
			0.15-0.22		3	Triangular
N^{5+}	0.27	Nitrate, NO_3-		0.2142	3	
C^{4+}	0.30	Carbonate, CO_3^{2-}		0.23	~3	
B^{3+}	0.15-0.41	Borate, BO_3^{3-}		0.119--0.325	3,4	
			0.22-0.41		4	Tetrahedral
P^{5+}	0.31-0.52	Phosphate, PO_4^{3-}		0.246-0.41	4	
Si^{4+}	0.34-0.48	Silitcate, $SiO_4$2-		0.25-0.36	4	
Cr^{+6}	0.40-0.58	Chromate, CrO_4^{4-}		0.317-0.46	4,6	
S^{4+}	0.43	Sulfate, SO_4^{2-}		0.3412	4	
As^{5+}	0.475-0.60	Arsenate, AsO_4^{3-}		0.376-0.476	4,6	
V^{5+}	0.495-0.68	Vanadate, VO_4^{2-}		0.392-0.539	4,6	
Mo^{+6}	0.55-0.87	Molybdate, MoO_4^{2-}		0.343-0.69	4,6	
W^{+6}	0.56-0.74	Tungstenate, WO_4^{2-}		0.44-0.58	4,6	
			0.41-0.73		6	Octahedral
Al^{3+}	0.47-0.61			0.36-0.46	4,6	
Fe^{3+}	0.57-0.68			0.43-0.52	6	
Mg^{2+}	0.80-0.97			0.61-0.73	6,8	
Pb^{4+}	0.915			0.726	6,8	
Fe^{2+}	0.71-0.77			0.54-0.58	6	
			0.73-1.0		8	Cubic
Mn^{2+}	0.83-1.01			0.63-0.77	6,8	
Na^{+}	1.10-1.24			0.76-0.94	8	
Ca^{2+}	1.08-1.20			0.82-0.91	8	
Th^{4+}	1.08-1.35			0.79-0.1.07	8	
U^{4+}	1.03-1.31					
Sr^{2+}	1.32			1.04	8	
Pb^{2+}	1.33			1.04	8	
			>1.0		12	Dodecahedral
Ba^{2+}	1.49			1.17	12	
K^{+}	1.59-1.68			1.20-1.27	12	

Table B.10: Common Ionic Crystal Unit Cells

Structure	Unit cell	Coor. #	Sulfides	Ion	radii
sodium chloride	fcc	6	PbS	S^{2-}	170
cesium chloride	cubic	8	Ag_2S	Ag^+	142
zinc blende (ZnS)		4	Cu_2S	Pb^{2+}	133
wurtzite (ZnS)		4		Cu^+	74
fluorite CaF_2		8 cation, 4 anion			
rutile (TiO_2)		6 cation, 3 anion			

Table B.11 ($M_2^{2+}(CO_3)_2$)

	Hexagonal		Orthorhombic	
	Ca^{2+}	Mg^{2+}	Pb^{2+}	Ca^{2+}
a	4.99Å	4.84Å	5.15Å	4.95Å
b			8.47Å	7.96Å
c	17.04Å	15.96Å	6.11Å	5.73Å
r (pm)	1.08-1.20	0.8-0.97 1.12-1.33Å		

Table B.12: Common Mineral Classes

Mineral Classes	Common Anions	Comments
Silicates	SiO_4^{4-}	
Framework		Quartz
Feldspar group		
Alkali Feldspar		Orthoclase KalSi3O8
Plagioclase Fledspars		Albite NaAlSi3O8
Sheet		Clays
Chain		
Sulfides	S^{2-}	
Tetrahedral Group		Chalcopyrite ($CuFeS_2$): tetragonal
Octahedral Group		Galena PbS ;cubic
Halides	F^-, Cl^-, Br^-, I^-	
Oxides	O^{2-}	
Tetrahedral		ZnO; hexagonal close pack
Rutile		TiO_2; tetragonal
Hydroxides	OH^-	Gibbsite ($Al(OH)_3$
Carbonates, Nitrates	CO_3^{2-} NO_3^-	
Calcite Group		$CaCO_3$; hexagonal
Dolomite Group		$CaMg(CO_3)_2$
Aragonite Group		$CaCO_3$; orthorhombic
		$PbCO_3$; orthorhombic, rare
Nitrate Group		Saltpetre (KNO_3)
Borates	BO_3^{3-} or BO_4^{5-}	Mostly rare
Sulfates	SO_4^{2-}	100 minerals known
Tungstates, Molybdates, Chromates	WO_4^{2-}, MoO_4^{2-}, CrO_4^{2-}	Rare minerals related to anhydrous sulfates
Phosphates, Arsenates, Vanadates	PO_4^{3-}, AsO_4^{3-}, VO_4^{3-}	Only apatite: $Ca_5(PO_4)_3(F,Cl,OH)$

Table B.13: Minerals Important in the History of Lead

Class	Formula	Structure	Uses
Sulfides			
Galena	PbS	Cubic	Mined, Egyptian Kohl
Altaite	PbTe	Cubic	IR Sensors
Clausthalite	PbSe	Cubic	IR Sensors
Oxides			
Litharge	αPbO		
Massicot	βPbO	Orthorhombic	Paint
Minium	$Pb^{2+}{}_2Pb^{4+}O_4$	Tetragonal	Red paint
	$Pb^{2+}{}_2Sn^{4+}O_4$		Giallino = Lead Tin Yellow I, non-native
Plattnerite	PbO_2	Tetragonal	Batteries
Pyrochlore	$\mathbf{A_{1\text{-}2}B_2O_6(O,OH,F)\text{-}nH_2O}$		
Bindheimite	$Pb_2Sb_2O_6(O,OH)$ Cubic		=Naples Yellow
	$PbSn_{1-x}Si_xO_3$		Lead Tin Yellow II, non- native
Carbonates			
Cerrussite	$PbCO_3$	Orthorhombic	Silverstone, White Paint
Acetates			
	$Pb(CH_3COO)_2$		Sugar of lead: fungicide, sweetner
Sulfates			
Anglesite	$PbSO_4$	Orthorhombic	Batteries, additive to yellow chrome
Plumbojarosite	$PbFe^{3+}{}_6(SO_4)_4(OH)_{12}$	Trigonal	Mined
Tungstates, Molybdates and Chromates			
Crocoite	$PbCrO_4$	Monoclinic	Rare: Yellow chrome
Wulfenite	$PbMoO_4$	Tetragonal	Additive to yellow chrome
Apatite Group:	$\mathbf{Ca_5(PO_4, CO_3)_3(F,Cl,OH)}$		
Pyromorphite	$Pb_5(PO_4)_3Cl$	Hexagonal	Used to stabilize lead in soil

Table B.14 Lead Minerals, Part I

Silicates			
Iranite	$Pb_{10}Cu(CrO_4)_6(SO_4)(OH)_6$	Triclinic	
Kasolite	$Pb(UO_2)SiO_4 \cdot H_2O$	Monoclinic	
Sulfides			
Galena	PbS	Cubic	$320 million (1858-1958 US)
Altaite	PbTe	Cubic	
Clausthalite	PbSe	Cubic	
Sulfosalts = Pb,Cu,Ag + S + Sb, As, Bi			
aikinite	$PbCuBiS_3$	orthorhombic	
andorite	$PbAgSb_3S_6$	orthorhombic	
Berryite	$Pb_3(AgCu)_5Bi_7S_{16}$	monoclinic	
Baumhauerite	$Pb_3As_4S_9$		
Boulangerite	$Pb_5Sb_4S_{11}$	monoclinic	
Bournonite	$PbCuSbS_3$	orthorhombic	
Buckhornite	$AuPb_2BiTe_2S_3$	orthorhombic	
Cosalite	$Pb_2Bi_2S_5$	orthorhombic	
cuproparonite	$AgPbCu_5Bi_5S_{10}$	monoclinic	
Eskimoite	$Ag_7Pb_{10}Bi_{15}S_{36}$	Monoclinic	
Fizelyite	$Pb_{14}Ag_5Sb_{21}S_{48}$	Monoclinic	
Freieslebenite	$PbAgSbS_3$	Monoclinic	
Friedrichite	$Pb_5Cu_5Bi_7S_{18}$	Orthorhombic	
Fülöppite	$Pb_3Sb_8S_{15}$	Monoclinic	
Galenobismutite	$PbBi_2S_4$	Orthorhombic	
Geocronite	$Pb_5(Sb,As)S_8$	Monoclinic	
Guettardite	$Pb(Sb,As)_2S_4$	Monoclinic	
Gustavite	$PbAgBi_3S_6$	Orthorhombic	
Heyrovskyite	$Pb_{10}AgBi_5S_{18}$	Orthorhombic	
Jamesonite	$Pb_rFeSb_6S_{14}$	Monoclinic	Brittle Feather Ore
Jordanite	$Pb_{14}(As,Sb)_6S_{23}$	Monoclinic	
Kobellite	$Pb_{22}Cu_4(Bi,Sb)_{30}S_{69}$	Orthorhombic	
Krupkaite	$PbCuBi_3S_6$	Orthorhombic	
Lillianite	$Pb_3Bi_2S_6$	Orthorhombic	
Nagyagite	$Pb_5Au(Te,Sb)_4S_{5\text{-}8}$		
Neyite	$Pb_7(Cu,Ag)_2Bi_6S_{17}$	Monoclinie	
Nuffieldite	$Pb_2cu(Pb,Bi)Bi_2S_7$	Orthorhombic	
Ourayite	$Ag_{25}Pb_{30}Bi_{41}S_{104}$	Orthorhombic	
Owyheeite	$Ag_2Pb_7(Sb,Bi)_8S_{20}$	Orthorhombic	
Pavonite	$(Ag,Cu)(Bi,Pb)_3S_5$	Monoclinic	
Sartorite	$PbAs_2S_4$	Monoclinic	
Schirmerite	$Ag_3Pb_3Bi_9S_{18}$ to $Ag_3Pb_6Bi_7S_{18}$		
Semseyite	$Pb_9Sb_8S_{21}$	Monoclinic	
Tintinaite	$Pb_{22}Cu_4(Sb, Bi)_{30}S_{69}$	Orthorhombic	
Treasurite	$Ag_7Pb_6Bi_{15}S_{32}$	Monoclinic	
Vikingite	$Ag_5Pb_8Bi_{13}S_{20}$	Monoclinic	
Zinkenite	$Pb_6(Sb,As)_{12}S_{24}$	Hexagonal	

Table B.14: List of Lead Minerals, Part II

Halides			
Oxides and Hydroxides			
Coronadite	$Pb(Mn^{4+},Mn^{2+})_8O_{16}$	Monoclinic	
Curite	$Pb_3U_8O_{24}(OH)_6 \cdot 3H_2O$	orthrorhombic	
Fourmarierite	$Pb(UO_2)_4O_3(OH)_4 \cdot 4H_2O$	Orthorhombic	
Massicot	PbO	Orthorhombic	
Minium	$Pb^{2+}{}_2Pb^{4+}O_4$	Tetragonal	
Molybdomenite	$PbSeO_3$	Monoclinic	
Plattnerite	PbO_2	Tetragonal	(Common, but inconspicuous in mine tailings derives from photooxidation)
Vandendriesscheite			
	$PbU_7^{6+}O_{22} \cdot 12H_2O$	orthorhombic	
Wölsendorfite	$(Pb,Ca)U_2O_7 \cdot 2H_2O$	Orthorhombic	
Pyrochlore Group ($A_{1\text{-}2}B_2O_6(O,OH,F) \cdot nH_2O$		**Cubic**	
Bindheimite	$Pb_2Sb_2O_6(O,OH)$		Cubic
Plumbopyrochlore	$(Pb,Y,U,Ca)_{2\text{-}x}Nb_2O_6(OH)$		Cubic
Lead/Tin Yellow			Not a “native” mineral
Carbonates and Nitrates			
Caledonite	$Pb_5Cu_5(CO_3)(SO_4)_3(OH)_6$		
Cerrussite	$PbCO_3$	Orthorhombic	Silverstone, found with galena
Leadhillite	$Pb_4(SO_4)(CO_3)_2(OH)_2$	Monoclinic	
Phosgenite	$Pb_2(CO_3)Cl_2$		Found with cerrussite, and Sr/cerrussite
Borates			
Sulfates			
Anglesite	$PbSO_4$	Barite group	$PbS \rightarrow PbSO_4$, $BaSO_4 \rightarrow PbCO_3$
Beaverite	$Pb(Cu,Fe,Al)_3(SO_4)_2(OH)_6$	Trigonal	
Lanarkite	$Pb_2(SO_4)O$	Monoclinic	
Linarite	$PbCu(SO_4)(OH)_2$	Monoclinic	
Osurizawaite	$PbCuAl_2(SO_4)_2(OH)_6$	Trigonal	Fracture filling of galena/sphalerite
Plumbojarosite	$PbFe^{3+}{}_6(SO_4)_4(OH)_{12}$	Trigonal	
Tungstates, Molybdates and Chromates			
Crocoite	$PbCrO_4$		Ural Mountains
Wulfenite	$PbMoO_4$	Tetragonal	
Phosphates, Arsenates, and Vanadates			
Corkite	$PbFe^{3+}{}_3(PO_4)(SO_4)(OH)$	Trigonal	
Dumontite	$Pb_2(UO_2)_3O_2(PO_4)_2 \cdot 5H_2O$	Monoclinic	
Grayite	$(Th,Pb,Ca)PO_4 \cdot H_2O$	psuedohexagonal	
Hinsdalite	$(PbSr)Al_3(PO_4)(SO_4)(OH)_6$	Trigonal	
Plumbogummite	$PbAl_3(PO_4)_2(OH)_5 \cdot H_2O$	Trigonal	
Bayldodnite	$PbCu_3(AsO_4)_2(OH)_2.H_2O$	Monoclinic	
carminite	$PbFe^{3+}{}_2(AsO_4)_2(OH)_2$	Orthorhombic	
Duftite	$PbCu(AsO_4)OH$	Orthorhombic	
Brackebuschite	$Pb_2(Mn^{2+},Fe^{2+})(VO_4)_2 \cdot H_2O$		
Descloizite	$PbZn(VO_4)OH$	Orthorhombic	
Apatite Group: $Ca_5(PO_4, CO_3)_3(F,Cl,OH)$			
Mimetite	$Pb_5(AsO_4)_3Cl$	Monoclinic	
Pyromorphite	$Pb_5(PO_4)_3Cl$	Hexagonal	
Vanadinite	$Pb_5(VO_4)_3Cl$	Hexagonal	

Table B.15 Lead Content of Rocks

Rock Type		Average lead content µg/g
Igneous	gabbro	1.9
	Andesite	8.3
	Granite	22.7
Sedimentary	Shales	23
	Sandstones	10
	Limestones	7

Table C.1 Cation Exchange Parameters for Soils and soil components

Material	Location	meq/100g
Sand		1-5
Silt loams		15-30
Kaolinite clay		3-15
Illite clay		25-40
Montmorillonite clay		60-100
Humus		100-300
Surface Soil	Location	meq/100g
charlotte fine sand	Florida	1.0
Ruston fine Sandy loam	Texas	1.9
Gloucester loam	New Jersey	11.9
Grundy silt loam	Illinois	26.3
Gleason clay loam	California	31.6

Table C.2: Input of Minerals From Rock Weathering

kg/ha-yr

Location	K	Ca	Mg	Na	Source
Long Island	11.1	24.3	8.3	6.7	Woodwell and Whittaker, 1967
New Hampshire	4.0	8.0	8.0	-	Likens et al, 1970
Washington State		15.2	17.4	-	- Cole et al, 1967

Table C.3: Input of Minerals From Atmospheric Dust

Kg/ha-yr

Location	K	Ca	Mg
Wisconsin	1-4	2-7	0.5-1.1
Great Britain	2.8	6.7	6.1
Belgium	2.9	9.1	2.3
Germany	4.6	19	-
Nigeria	17.5	12.7	11.3
Mississippi	4	5	1
Sweden	0.6-3.7	2.6-13.9	0.6-2.6
N. Carolina	0.3	0.9	0.7

Table C.4

Weathering losses from continents to the Sea (continental land area = $1.2x10^8$ km^2)

Element moles/ha-yr	Soluble $x10^{12}$ moles/ year	Sediment moles/ha-yr	
Na	3.6	300	130
K	1.8	150	120
Mg	5.5	460	110
Ca	13	1100	130
Si	9	750	3300
Al	-	-	930
Fe	-	-	300
S	1.9	160	-
Cl	2.7	220	-

Table C.5 Ionic Composition of Sea and Average River in ppm or Molarity

Ion	Salton Sea **Geothermal Brine**	Ancient **Solution Utah**	**Present Ocean**		**Average River**
	Ppm	ppm	ppm	M	M
Cl^-	155,000	29500		0.55	$2.2x10^{-4}$
Na^+	50,400	152000		0.47	$2.7x10^{-4}$
Ca^{2+}	28,000	4,400		$1.0x10^{-2}$	$3.8x10^{-4}$
K^+	17500	67,000		$1.0x10^{-2}$	$5.9x10^{-5}$
Mg^{2+}	54			$5.4x10^{-2}$	$3.4x10^{-4}$
B	390				
Br	120				
F^-	15			$7x10^5$	$5.3x10^{-6}$
NH_4^+	409				
HCO_3^-	>150				
H_2S	16				
SO_4^{2-}	5	11,000		$2.8x10^{-2}$	$1.2x10^{-4}$
Fe	2290	8,000	0.001-0.15		
Mn	1400		0.0007-0.01		
Zn	450		0.001-0.021		
Pb	102		0.0003-0.005		
Cu	8				

Table C.6: Concentration of Metals in Ocean and Freshwater

Element	Ocean Concentration µg/L	Range µg/L	Species	FreshWater Concentration µg/L	Range µf/L	Species
As	3.7	0.5-3.7	$HAsO_4^{2}$-, H_2AsO_4-	0.5	0.2-230	anionic
Bi	0.02	0.0157-0.02	BiO^+	0.02?		
Cd	0.11	0.01-9.4	$CdCl_2$, Cd^{2+}	0.1	0.01-3	organic
Hg	0.03	0.01-0.22	$HgCl_2$, $HgCl_4^{2-}$	0.1	0.0001-2.8	
Pb	0.03	0.03-13	$PbCl^+$, $PbCl_3^-$	3	0.06-120	
Sb	0.3	0.18-5.6		0.2	0.01-5	
Se	0.2	0.052-0.2		0.2	0.02-1	

Table C.7. Typical Groundwater concentrations

Species	ppm
Ca^{2+}	2130
Na^+	1900
Mg^{2+}	61
K^+	14
Cl^-	6086
SO_4^{2-}	1040
HCO_3-	68

Table C.8: Lead Content of Urban Soils

Location	date	arithmetic mean, ppm
Durham, NC	1974	19.4
Pine Bluff, AK	1974	21.5
Grand Rapids, MI	1976	27.1
Sikeston, MO	1976	27.1
Mobile, AL	1976	28.8
Greenville, SC	1973	28.9
Augusta, ME	1976	31.0
Evansville, IN	1973	53.6
Manhattan, KA	1975	67.1
Honolulu, HA	1976	67.9
Houston, TX	1975	76.5
Sioux City, IA	1976	80.8
Cheyenne, WY	1976	82.7
Springfield, IL	1974	96.6
Greenville, MS	1976	98.9
Portland, OR	1976	98.9
Salt Lake City, UT	1975	120.5
Gary, IN	1974	132.5
Waterbury, CT	1976	136.4
Bakersfield, CA	1975	147.0
Miami, FL	1975	150.8
Milwaukee, WI	1975	150.6
Memphis, TN	1976	154.6
Pittsfield MA	1973	156.2
San Francisco, CA	1974	179.1
Tacoma, WA	1973	202.8
Washington DC	1973	206.6
Wilmington, DE	1976	250.9
Richmond, VA	1976	256.8
Philadelphia, PA	1976	306.4
Charleston, SC	1976	415.3
Camden NJ	1975	536.8
Chicago, IL	1987	276
Suburbs, Chicago	1987	156
Downstate, IL	1987	82

Table C.9: Lead Content of Select Soils

Location	ppm
Remote Canada	5-20
Rural Canada	10-50
New Brunswick	0-100
UK uncontaminated	10-150
Ontario, rural	5-360
UK London	671
Inner-city, Canada	150-3000
UK 18th mining area	3800
Homes Near Smelter	1,000-6,000
Toronto secondary smelter	21200
Smelter, Canada	30,000
US Missouri lead belt	30,400

Table C.10: Amount of Minerals Removed by Species

	kg/ha		
	K	Ca	Mg
Northern Hardwood (45-50 yr)	60	241	24
Oak (47 yr)	118	173	23
Beech (37 yr)	96	117	-
Loblolly pine (16 yr)	89	112	29
Spruce-fir	47	150	14

Table C.11: Potash (KCO_3) production by tree species

5 Tons of:	Pounds of Potash
Pine	8
Maple	18.1
Elm	39

Table C.12: Biological Selectivity for Calcium: Ca/M

M	rock/soil		rock/plant	soil/plant	plant/herbivore
Ca	1		1	1	
Sr		2.6		4.1	
Ba		16		7.7	
Pb	7.6		13	16	

Table C.13

Transfer of Soil Lead to Plants

Element	Transfer Coef. Plant/Soil	Critical Concen. for plant growth
Cd	1-10	5-10
Tl	1-10	20-30
Pb	0.01-0.1	10-20
Zn	1-10	150-200
Cu	0.1-1	15-20
Ni	0.1-1	20-30
Cr	0.01-0.1 1-2	

Table C.14: Lead in Mexico City Vegetation

Site	Lead, ppm Unwashed leaves	Washed
Aeropuerto	564	19.7
Azcapotzalco	280	13.2
Viaducto	188	11.0
Tlalpan-Centro	164	12.0
Gustavo Madero	171	0.0
Reinferia	120	6.7
Iztacalco	123	2.7
Periferico Norte	87.6	5.6
Tlalpan-Ermita	65.0	0.0
Insurgentes-Reforma	48.5	0.0
Centro	37.5	1.0
Estadio Azteca	35	0.0
Carr. Mex. Toluca	38.5	0.0
Churubusco-Ermita	34	1.7
Xochimilco	7.6	1.2
Milpa Alta	2.6	0.0
Desierto de los Leones	1.5	-

Table C.15 Fuel Content of Various Materials

Material	C (wt%)	MJ/dry kg	%K_2O
Municipal Waste		12.7	
Cellulose	44.44	17.51	
White Birch		19.37	
Red Maple		19.5	
Eastern White Cedar		19.5	
Beech		19.65	
Primary Biosolids (Sewage Sludge)	43.75	19.86	
Oak		19.20	
Poplar			20.00
Birch		20.03	
Beech		20.07	
Sawdust	46.84	20.4	
Eastern Hemlock		20.65	
White Spruce		20.66	
Jack Pine		20.68	
Peat		20.8	
Pine Wood	51.8	21.24	2.55
Douglas Fir Bark	55.7	22.36	
Sub Bituminous Coal	59.9	24.7	
Lignin	63	25.1	
Charcoal		28.33	
Charcoal		30.2	
Bituminous coal	69	28.28	
Bituminous Coal	73.01	30.47	
Anthracite coal		29.47	
Isooctane Gas		36.5	
Crude Oil		48.20	
Natural Gas		49.5	

conversions: 17.51 MJ/kg = 7533 Btu/lb

Klass, Donald L. Biomass for Renewable Energy, Fuels, and Chemicals
Academic Press, 1998
Tillman, D.A., Wood as an Energy Source, 1978

Table D..1: Solubility Rules

	Anion	Radius pm	Charge	Charge/r^3	Exceptions
Soluble					
	Nitrate, NO_3^-	189	1	$1.48x10^{-7}$	
	Sulfate, SO_4^{2-}	230	2	1.64	AgCl, Hg_2Cl_2, $PbCl_2$
	Chloride, Cl^-	167	1	2.14	Sr, Ba, Pb insoluble
	Acetate, CH_3COO^-	159	1	2.48	
Insoluble					
	Carbonate, CO_3^{2-}	185	2	3.158	Group 1, NH_4^+
	Hydroxide, OH^-	140	1	3.64	Group 1, NH_4^+, Sr,Ba
	Sulfide, S^{2-}	170	2	4.07	Group 1,2 NH_4^+

Table D.2: Solubility of Pb^{2+} and Ca^{2+}

Salt	-Log Ksp Pb^{2+}	-Log Ksp Ca^{2+}
MCl_2	3.74	-3.08
MSO_4	7.75	4.21(est.)
MCO_3	13.5	8.3
$M(OH)_2$	15.6	5.2
$MCrO_3$	13.75	-0.037 (est.)
MO (yellow)	15.3	3.3
MS	29	5.11 (est.)
$M_3(PO_4)_2$	42.1	28.7
MO_2	insoluble	not applicable
ionic radius	0.175 nm	0.197 nm

Table D.3: Solubility of Soil Lead Minerals

Mineral	Formula	$logK_{sp}$	Ppm in stomach fasting/fed	Comments
Litharge	PbO	12.9	100%/100%	paint derived
Anglesite	$PbSO_4$	-7.7		ore,gasoline derived
Cerrusite	$PbCO_3$	-12.8	150/0.49 ppm	ore, paint, gasoline
Galena	PbS	-27.5		
Pyromorphites	$Pb_5(PO_4)_3F$	-71.6		
	$Pb_5(PO_4)_3OH$	-76.8		
	$Pb_5(PO_4)_3Br$	-78.1		
	$Pb_5(PO_4)_3Cl$	-84.4	80/0.01 ppm	
Hinsdalite	$PbAl_3(PO_4)(SO_4)(OH)_6$	-99.1		
Plumbogummite	$PbAl_3(PO_4)_2(OH)_5{\cdot}H_2O$	-99.3		
Corkite	$PbFe(PO_4)(SO_4)(OH)_6$	-112.6		

Table D.4.

Solubility	Bone Mineral		Molar Ca/P	density
Most	$Ca(HPO_4)2H_2O$	dicalcium phosphate dihydrate (DCPD) Brushite	1.00	2.306
	$Ca_4H(PO_4)_3$	octacalcium phosphate (OCP)	1.33	
	$Ca_9(PO_4)_6$(var)	amorphous calcium phosphate (ACP)	1.3-1.5	
	$Ca_3(PO_4)_2$	Tricalcium phosphate (TCP) Whitlockite	1.5	3.14
Least	$Ca_5(PO_4)_4OH$	hydroxyapatite (HAP)	1.67	

Table D.5:

Solubility (g/100 mL) of Various Salts

Salt	Hot Water	Cold Water
$LiNO_3$		89.8
$NaNO_3$ (soda niter)		92.1
KNO_3	247	13.3
$RbNO_3$		44.28
$CsNO_3$		9.16
$Mg(NO_3)_2$		125
$Ca(NO_3)_2 \cdot 4H_2O$	660	266
$Ca(NO_3)_2$	376	121.6
$Sr(NO_3)_2$		70.9
$Ba(NO_3)_2$		8.7
K_2CO_3	156	112
$CaCO_3$	0.00190	0.00153

Table D.6: Solubility of Metals in Mercury

Metal	phase	Formula	Structure	a (Å)	solubility (wt%)
Au		Au_3Hg_3			0.13
Ag	γ	Ag_5Hg_8	γbrass	10.04	0.03
	ε	$AgHg_3$	h.c.p.	2.98	
Cu	γ	Cu_5Hg_8	cubic	4.49	0.002
Sn	γ	$Sn_{12}Hg$	hexagonal	3.214	0.6
Pb		Pb_2Hg_2	f.c.tetragonal	4.972	1.5

Table D.7
Heat of Formation

Compound	**kJ/mol** ΔH^o_f	**J/mol** ΔG^o_f	S^o
Pb(s)	0	0	0
Pb^{2+}(aq)	-1.7	-24.4	10.5
PbO(s)	-219	-188.9	66.5
PbO_2(s)	-277	-217	69
PbS(s)	-100	-99	91
$PbSO_4$(s)	-920	-813	149
C(s, graphite)	0	0	0
CO(g)	-110.5	-137	198
CO_2(g)	-393.5	-394	214
S(s,rhombic)	0	0	32
H_2S(g)	-21	-34	206
S_8(g)	102	50	431
SO_2(g)	-297	-300	248
O_2(g)	0	0	205
Cu_2O(s)	-170	-148	93
Cu(s)	0	0	33
$TiO_{2(solid)}$	-945		50
Ti	485		179.45
$HNO_{3(l)}$	-174		
$NO_{2(g)}$	34		
$H_2O_{(l)}$	-		

Table D.8
Heat of Fusion of Several Materials

Material	cal/g	kJ/mol
Sn	14.4	6.729
Cu	49.0	13.02
Pb	5.9	5.114
PbF_2	7.6	7.796
$PbCl_2$	20.3	23.62
$PbBr_2$	11.7	17.96
PbI_2	17.9	34.52
PbO	12.6	11.76
PbS	17.3	17.31

Table D.8: Reduction Potentials	
Reaction	V
$PbO_2 + 4H^+ + SO_4^{2-} + 2e \rightarrow PbSO_4 + 2h_2O$	1.69
$Au^{3+} + 3e \rightarrow Au$	1.50
$PbO_2 + 4H^+ + 2e \rightarrow Pb^{2+} + 2H_2O$	1.46
$Cr_2O_7^{2-} + 14H^+ + 62 \rightarrow 2Cr^{3+} + 7H_2O$	1.33
$O_{2(g)} + 4H^+ + 4e \rightleftharpoons 2H_2O$	1.229
$AuCl_4^- + 3e \rightarrow Au + 4Cl^-$	0.99
$Ag^+ + e \rightarrow Ag$	0.80
$Fe^{3+} + e \rightleftharpoons Fe^{2+}$	0.771
$O_{2(g)} + 2H^+ + 2e \rightleftharpoons H_20$	0.682
$Cu^+ + e \rightarrow Cu$	0.52
$O_2 + 2H_2O + 4e \rightarrow 4OH^-$	0.40
$Cu^{2+} + 2e \rightarrow Cu$	0.337
$AgCl + e \rightarrow Ag + Cl^-$	0.22
$Cu^{2+} + e \rightarrow Cu^+$	0.16
$2H^+ + 2e \rightarrow H_2$	0
$Pb^{2+} + 2e \rightarrow Pb$	-0.126
$Sn^{2+} + 2e \rightarrow Sn$	-0.136
Pb^{2+}citrate +2e ⇋ Pb + citrate	**-0.1428**
$Ni^{2+} + 2e \rightleftharpoons Ni$	-0.246
$PbSO_4 + 2e \rightarrow Pb + SO_4$	-0.35
$Fe^{2+} + 2e \rightarrow Fe$	-0.440

Table D.9 Complexation of Metals with Chloride, Cl^-

Metal	$\log K_{f1}$	$\log K_{f2}$	$\log K_{f3}$	$\log K_{f4}$
Ag^+	3.70	1.92	0.8	-0.3
Cu^+	2.70	3.30	0.0	
Cd^{2+}	1.98	0.6	-0.2	-0.7
Hg_2^{2+}	6.74	6.48	0.9	1.0
Hg^{2+}	7.30	6.70	1.0	0.6
Pb^{2+}	1.55	0.6	-0.4	-0.7
Sn^{2+}	1.51	0.74	-0.25	-0.5
Zn^{2+}	0.43	0.5	-0.3	

Table D.10 Chelation Constants with Lead

Complex	Structure	logK
acetic Acid	C_3COOH	2.2
Fulvic acid		4.1
Citric acid		6.5
EDTA		18.3
MSA		27

Table D.11 Formation Constants

	EDTA	DMSA		
Metal	K ML	K (ML)	K (ML_2)	K M_2L
In^{2+}		4.8×10^{21}		
Cu^{2+}	6.31×10^{18}			
Ni^{2+}	3.98×10^{18}	4.9×10^{11}		4.4×10^{2}
Cd^{2+}	3.16×10^{18}			
Pb^{2+}	7.9×10^{17}	2.9×10^{17}	1.6×10^{27}	
Zn^{2+}	3.16×10^{16}	2.6×10^{4}	1.2×10^{4} 2.1×10^{3}	
Ca^{2+}	5.01×10^{10}			
Mg^{2+}	5.01×10^{8}			
Ba^{2+}	6.3×10^{7}			

Table D.12 Lead Chelation Data

		log K(ML) or K(MHL)						
Metal cation		Pb	Ca	Cd	Zn	Cu	Mg	Ni
ionic radii/pm		133	114	109	88	87	86	83
Chelate								
Name	Ligands							
pyrocatechol	O	13.25		8.13	10.41	16.47	4.42	9.35
Tiron	O	11.95	5.8	7.69	10.19	14.53	6.86	9.96
Betadiketones AA	O	8.6		7.79	9.52	12.46	3.36	5.96
Betadiketones BzA	O	8.84		12.02	9.62	9.42	7.84	10.3
Betadiketones Dbm	O	9.75		8.67	10.23	12.98	8.54	10.83
Sulfarsazen	N, O	10.5		9.8	10.8	5.09		8.1
PAR	N, O	11.9		10.5	10.5	14.8		13.2
TAR	N, O	8.34	3.5	6.96	7.19	11.56	<3	12.94
EDTA	N, O	18.04	10.96	16.46	16.5	18.80	8.69	18.62
MTB	N, O	6.4	5.5	3.3	5.5		5.2	
Alizarin	N, O	11.69			12.19	14.75		12.23
8-hydroxyquinoline	N, O	10.61	7.3	9.43	9.96	13.49	6.38	11.44
nitrosnaphtaline	N, O	9.73		6.18	9.32	12.52	6.05	10.75
dioxime	N	7.3		5.7	8.1	11		11.16
thioxine	S N	11.52		10.79		12-14		10.95
diethyldithiocarbamate	S	18.3			11.4	28,8		12.9

Table: D.13: Chemical Equilibrium Constants Important in the Patio Process

Compound	K_{sp}	K_1		K_2		K_3	K_4		
CuS	$1.25x10^{36}$								
$CuSO_4$		$2.18x10^2$							
$CuCl_2$		2.5							
CuCl	$1.2x10^{-6}$	501		$1.99x10^3$			1		
Ag_2S	$6x10^{-50}$								
AgCl	$1.82x10^{-10}$	$5.01x10^3$			83.1		6.3	0.501	
$HgCl_2$		$1.99x10^7$			$5.0x10^6$		10	3.98	
Hg_2Cl_2	$1.3x10^{-18}$		$5.49x10^6$			$3.0x10^6$		7.94	10

	E^o (vs NHE)
$Ag^+ + e \leftrightharpoons Ag$	0.80
$Cu^{2+} + e \leftrightharpoons Cu^+$	0.16
$Hg^{2+} + 2e \leftrightharpoons Hg_{liquid}$	0.852
Ag_2Hg	amalgam

Table D.13: Temperature (°C) Required to Reach a Variety of Vapor Pressures

Species	mm: m.p. C	1	10	40	100	400	760
Pb	327.5	973	1162	1309	1421	1631	1744
$PbBr_2$	373	513	610	686	745	856	914
$PbCl_2$	501	547	648	725	784	893	954
PbF_2	855	solid	904	1003	1080	1219	1293
PbI_2	402	479	571	644	701	807	872
PbO	890	943	1085	1189	1265	1402	1472
PbS	1114	852(s)	975(s)	1048(s)	1108(s)	1221	1281

Table D.13

Vapor Pressure: Lead, Lead Compounds, and Water

torr	T (°C)							
	PbF_2	$PbCl_2$	$PbBr_2$	PbI_2	PbO	PbS	Pb	H_2O
1		547	513	479	943	975s	973	-17.3s
10	904	648	610	571	1085	975s	1162	11.3
40	1003	725	686	644	1189	1048s	1309	34.1
100	1080	784	745	701	1265	1108s	1421	51.6
400	1219	893	856	897	1402	1221	1630	83
760	1293	954	914	872	1472	1281	1744	100
m.p. (°C)	818	500	367	400	890	1114	327.5	0
b.p. (°C)	1290	953	916	860-950		1740	100	
density(g/cm$^{3)}$	8.24	5.85	6.66	6.2	8.0-9.1	7.5	11.34	1

Table D.13

Vapor Pressure Over Pb and Sn Compared

mm Hg	Pb (°C)	Sn (°C)
1	9973	1492
10	1162	1703
40	1302	1855
100	1421	1968
400	1630	2168
760	1744	2270
m.p.	327.5	231.9

Table D.14: Boiling Points

d=decompose, subl= sublimes

Metal, Row 4	chlorides	oxides (m.p.)	nitrates
K^+	subl 1500	d 350	d 400
Ca^{2+}	>1600	2850	d 132
Cr^{3+}	subl 1300	4000	d 100 $Cr(NO_3)_3$-9H_2O
Zn^{2+}		1190	129.4 $Mn(NO_3)_3$-4H_2O
Fe^{3+}	d 315	(1565)	d 125 $Fe(NO_3)_3$-9H_2O
Co^{2+}	1049	(1795)	55 $Co(NO_3)_2$-6H_2O
Ni^{2+}	subl 973	(1984)	136.7 $Ni(NO_3)_2$-6H_2O
Cu^{2+}	d 993 to CuCl	(1326)	-HNO_2, 170
Zn^{2+}	732	(1975)	-6H_2O, 105-131 $Zn(NO_3)_2$-6H_2O
Pb^{2+}	950	(886)	d (470)
Cd^{2+}	960	sub 1559	132 $Cd(NO_3)_2$-4H_2O

Table D.15

Ore	formula	density (g/cm^3)	melting pt^o C	boiling pt^o C
malachite	$CuCO_3 \cdot Cu(OH)_2$	4.0	Decomposes 200	
azurite	$2CuCO_3 \cdot Cu(OH)_2$	3.88	Decomposes 220	
Cuprite	Cu_2O	6.0	1235	1800
chalcocite	Cu_2S	5.6	1100	...
Cu	Cu	8.92	1083	2567

Table D.16

Electronegativities

Li	1.0			C	2.5	N	3.0	O	3.5
Na	0.9	Mg	1.2	Si	1.8			S	2.5
K	0.8	Ca	1.0						
		Sr	1.0	Sn	1.8				
		Ba	0.9	Pb	1.9				

Table D.17

ΔE.N.	%ionic bond	%covalent bond
0	0	100
1.1	25	75
1.7	50	50
2.4	75	25
3.5	100	0

Table D.18

Element	Compound	electrons	melting point	sol(g/100cc)	refractive index
Sodium	NaCl	[Ne]$3s^1$	801	35.7	1.5442
Antimony, Sb	$SbCl_3$	[Kr]$5s^2 4d^{10} 5p^3$	73.4	601.6	-
	Sb_2O_5 (cervantite)		-0.93	v sl s	2.00
	Sb_2O_3 (Valentinite)		656	v sl s	2.18
Barium, Ba	$BaCl_2$	[[Xe]$6s^2$	962	37.5	1.73
	$BaCO_3$ (witherite)		1740	0.002	1.67
	BaO		1918	3.48	1.98
Bismuth, Bi	$Bi_2O_2CO_3$	[Xe]$6s^2 4f^{14} 5d^{10} 6p^3$	-	i	-
	$BiCl_3$		230	d to BiOCl	
	Bi_2O_3		860	i	1.91
Calcium, Ca					
Lead, Pb	$PbCO_3$	[Xe]$6s^2 4f^{14} 5d^{10} 6p^2$	315	0.00011	2.076
	$PbCl_2$		501	.99	2.26
	PbO_x range in colors yellow to red				
Magnesium, Mg	$MgCO_3$	[Ne]$3s^2$	d	0.04	1.527
	$MgCl_2$		714	54.25	1,675
Tin, Sn	$SnCl_4$	[Kr]$5s^2 4d^{10} 5p^2$	-33	s	1.512
	SnO_2 Cassiterite		1630	i	1.997
Titanium, Ti	$TiCl_2$	[Ar]$4s^2 3d^2$		Decomposes	
	$TiCl_4$ yellow				
	TiO_2 Anatase			I	2.554
Zinc, Zn	$ZnCO_3$ Smithsonite		-300	0.001	1.818
	$ZnCl_2$	[[Ar]$4s^2 3d^{10}$	283	432	1.681
	ZnO		1975	.00016	2.008

Table D.19 X-ray Transitions Observed with Lead

From/To	Å	From/To	Å
$L_{II}N_{III}$	.85192	M_{III},N_{IV}	4.715
$L_{II}N_V$	.8382	$\gamma M_{III},N_V$	4.674
$\upsilon L_{II}N_V I$	.82327	M_{III},O_I	4.244
$L_{II}O_{III}$	.8200	$M_{II},O_{I,vV}$	4.069
$tL_{III}M_{II}$	1.30767	$M_{IV},N_{II},$	6.802
$sL_{III}M_{III}$	1.24385	M_{IV},N_{III}	6.384
$L_{III}N_{II}$	1.01040	$\beta M_{IV},N_{II}$	5.076
$L_{III}N_{III}$	1.0005	M_{IV},O_{II}	5.004
$uL_{III}N_{VI,VII}$	0.96133	M_V,N_{III}	6.740
$L_{III}O_{II}$	0.9586	M_V,N_{VI}	5.299
$L_{III}O_{III}$	0.9578	M_V,N_{VII}	5.286
$L_{III},P_{II,III}$	0.95118	M_VO_{III}	5.168
M_I,N_{III}	3.872	$N_{IV}N_{VI}$	42.3
M_{II},N_I	4.655	$N_VN_{VI,VII}$	45.0
$M_{II,}N_{IV}$	3.968	$N_{VI}O_{IV}$	102.4
M_{III},N_I	5.704	$N_{VI}O_V$	100.2

Table D.20

Compound	Wavelength Absorbed	vibrational spectra
Lead Tin II Pb_2SnO_4	514.5 nm	35wm, 58w, 80m, 129vs (lattice Pb-O stretch mode), 274w, 291wm, 379w, 454wm, 524w, 613w.
Lead Tin I, $PbSn_{1-x}Si_xO_3$	514.5	40m, 66m, 85sh, 138vs (lattice Pb-O stretch mode) 324wm(br), 444w(br)
Lead Antimonate, $Pb_2Sb_2O_7$	514.5	76s, 147vs (lattice Pb-O stretch mode), 343s, 464m, 513wm

Table E.1: Roman Coin Metal Content

Type	Date	%Composition					
		Au	Ag	Cu	Sn	Zn	Pb
Roman Denaris	150 B.C.	0.53	94.34	4.40	0.23	-	0.39
Ptolemaic tetradrachm	1st century B.C.	0.24	52.51	40.45	1.74	0.11	1.36
Ptolemaic copper	169-146 -		65.11	5.12	0.1	28.78	
Brass	45 B.C.			71.1	-	27.6	-
Brass	A.D. 79			81.13	-	15.9	-
Brass	A.D. 161-162			88.96	2.43	7.87	0.18
As	AD 14-37			99.65	0.01	tr	tr
Antoninianus	AD 238-244	0.13	58.9	40.65	0.1	-	0.22
Denarius	AD 244-=249			98.36	1.03	-	0.51
Antonianus	AD 254-255		16.25	80.79	2.52	0.03	0.7
Carthage	AD 307		1.2	81.25	5,45	0.01	11.90
London	AD 310		1.76	86.78	5,.54	-	6.01
London	AD 318		2.11	87.89	4.33	0.01	5.57

Table E.2: Elemental Composition of Some Chinese Bronzes

Period	Object	Element, %				
		Cu	Sn	Pb	Fe	Sb
Shang-Yin1760-1120 B.C.						
	Axe head	79.66	16.67	trace	trace	-
Chou 1120-256 B.C.						
	Chisel	94.09	4.60	trace	0.53	-
	Statue	70.00	15.36	10.92	trace	-
	Dish	56.09	2.05	40.89	0.35	0.37
Ch'in 255-207 B.C.						
	Buckle	69.2	3.94	25.28	1.4	-
	Vase	84.39	11.68	1.48	0.79	0.59
	Pan	88.6	3.15	6.60	trace	-
Han 206 B.C.-220 A.D						
	Basin	82.39	14.36	3.24	-	-
	Mirror	70.50	26.97	1.65	0.12	0.34
	Buckle	73.33	11.52	7.24	trace	-

Table E.3: Metal Content of Various Mediterranean and Middle Eastern Objects

Source	Cu	Sn	Pb	Fe	As	Sb
			Element %			
Mycenae	90.76	8.42	0.32	0.54		
Nineveh	86.84	12.7	0.28	trace		
Macedonia	87.72	11.7	trace	0.27		
Early Greek	88.54	11.46				
Ptolemaic Egypt	75	13.15	11.4	trace		
Roman statue	78.3	10.7	10.24	0.14		
Britain	89.7	8.99	trace	0.16	0.68	0.15
Athens (520 B.C.)	88.1	9.7	0.3			
Sicily (600 B.C.)	90.3	7.3	0.3			

Table E.4 Elemental Composition of Objects from Harappa

Sample#	Fe	Pb	Cu	Sn	Ni
94497	0.76	1.37	82.87	15	
9514	1.4	3.0	86.3	12.3	
9531	Trace	3.6	90.1	33	
9722	Trace	0.86	76.12	22.2	0.75
9366	1.1	6.3	87.7	4.9	
9442	Trace	14.9	63	22.1	

Table E.5 Composition of Northern European Medieval Glass

Element	Colorless Westminster	Green Cluny	Blue Westminster
SiO_2	53.2	45.6	53.3
Al_2O_3	1.0	2.6	1.0
FeO	0.4	0.6	0.9
MnO	1.2	1.3	1.1
MgO	7.1	5.9	6.9
CaO	12.8	16.5	11.9
Na_2O	2.9	1.6	2.6
K_2O	17.1	15.3	17.0
P_2O_5	4.4	6.0	4.4
CuO	<0.4	2.8	0.4
CoO	<0.2	<0.2	0.2
PbO	<0.2	<0.2	0.2

Table E.6 Roman Glazes (100 B.C. to 100 A.D.)

Source	CaO	TiO_2	Fe_2O_3	CuO	PbO	SnO_2
Clear Glaze						
Colchester	4.9	0.4	2.2	0.02	62	0.02
Smyrna	3.2	0.2	2.7	0.02	56	0.2
Clazomenae	3.0	0.2	2.4	0.00	58	0.2
Tarsus	2.9	0.0	3.4	0.00	54	0.3
Green (Copper) Glaze						
Smyrna	4.1	0.1	1.0	4.2	53	1.0
Clazomenae	2.8	0.1	0.8	5.7	53	0.7
Tarsus	3.2	0.02	0.9	4.1	59	0.4

Table. E.7: River Meuse Enamels Compared to Roman Enamels

Material	Roman Turquoise	Mosan Turquoise	Roman Blue	Mosan Blue
SiO_2	66.36	64.9	66.60	66.1
Al_2O_3	2.16	2.1	2.42	2.2
FeO	0.65	0.6	1.17	1.2
MnO	0.10	<0.2	0.70	0.7
MgO	0.57	0.6	0.45	0.5
CaO	4.70	4.8	6.60	6.3
Na_2O	17.20	17.9	15.14	15.5
K_2O	0.60	0.3	0.59	0.5
CuO	2.83	3.0	0.28	<0.3
PbO	0.20	<0.3	0.59	1.1
Sb_2O_3	3.10	1.8	3.80	3.5
CoO	ND	<0.1	0.21	0.2
SnO_2	0.23	0.1	0.05	<0.1

Table E.8

Litharge Composition %

Data source: Craddock, P. T., 1995: *Early Metallurgy*

	Rio Tinto	Huelva	Saxon	1925 England
PbO	68.5	73.5	95.6	85.8
CuO	0.36	2.42	0.5	3.42
S	2.72	0.21	0.4	0.30
Sb	1.02	0.20	_	2.24
As_2O_2	0.89	0.06	-	-
Fe	4.89	1.9	–	0.17
Al_2O_3	1.33	–	–	
CaO	2.30	–	–	
MgO	0.45	–	–	
SiO_2	6.8	6.4	0.8	
Au	0.00034	0.00184		
Ag	0.0205	0.0568		

Table E.9: Roman lead and silver slags

Source: Tylecote, 1976: A History of Metallurgy.

%	Lead smelting Slags Ffwrndan	Silver Slag Laurion	Rio Tinto
PbO	32.3	10.70	1.5
SiO_2	58.2	33.8	26.2
CaO	8.0	13.8	
FeO	0.8	15.2	58.5
Ag	0.0004	0.06	0.00632
Zn		5.4	
Al_2O_3		3.9	
CuO			0.04

Table E.10 Composition of Egyptian Makeup (2000-1200 B.C.)

Sample	PbS Galena	$PbCO_3$ Cerussite	$Pb_2Cl_2CO_3$ Phosgenite	PbOHCl Lairionite
1	100			
2	50	13	37	
3	28	48	24	
4	43	27	29	1
5	12		72	16
6	62	28		10
7	24	25	16	35

source: Nature, 397, 11 Feb., 1999

Table F.1: **Some Typical Alloys**

Alloy	%Cu	%Zn	%Sn	%Pb	%Mn	%P	%Bi	%Sb	%Au	%Ag
Brass	20-97	2-80	0-14	0-12	0-25					
Bronze	50-98	0-29	0-35	0-50		0-3				
Pewter	7	85					6	2		
Pewter			70-95	0-15				5-15		
Plumbers Solder	33		67							
Sterling Silver	7.5									92.5
18 Carat Gold	5-15								75	10-20
14 Carat Gold	12-28								58	4-30

Table F.2, White Metals and Solders

Pewter

%Sn	%Sb	%Pb	%Cu
67-95	5-15	0-15	0-3

Modern Pewter

	%Sn	%Sb	%Pb	%Cu
casting	90-93	6-8	0.25-2	<0.05
sheet	90-93	5-7.5	1.5-3	<0.05
all purpose	95-98	1-3	1.0-2.0	<0.05

Typeset

%Sn	%Sb	%Pb	%Cu
15	25	60	trace

Babbitt Metals:

Alloy	%Sn	%Sb	%Pb	%As	density g/cn^3	Brinell Hardness at 100ºC	melting point ºC	Complete liquification ºC	Pouring C
#7	10	15	74.55	0.45	9.73	10.5	240	268	338
#8	5	15	79.55	0.45	10.04	9.5	237	272	341
#15	1	16	82	1.0	10.05	13.0	248	281	350

Table F.3: Types of Industrial Solder

Designation	%Sn	%Pb	%Sb	%Ag	Solidus T (C)	Liquidus T (C)	Use
Sn70	70	29.485	0.5	0.015	183	193	on Zn metals
Sn63	63	36.485	0.5	0.015	183	183	Sn/Pb eutectic, circuit boards
Sn62	62	35.94	0.06	2	179	189	on Ag
Sn60	60	39.485	0.5	0.015	183	190	electric connections
Sn50	50	49.485	0.5	0.015	183	216	all purpose: electrical, sheet metals
Sn45	45	54.485	0.5	0.015	183	227	all purpose
Sn40A	40	59.485	0.5	0.015	185	238	wiping solder for joining lead pipe
Sn40B	40	57.985	2	0.015	185	231	Same, but not on galvanized iron
Sn35A	35	64.485	0.5	0.015	183	247	Plumber’s solder with no antimony
Sn35B	35	62.985	2	0.015	185	243	Plumber’s solder
Sn30A	30	69.485	0.5	0.015	183	253	Autobody
Sn30B	30	67.985	2	0.015	185	250	Autobody dent filling
Sn25A	25	69.485	0.5	0.015	183	266	
Sn25B	25	67.985	2	0.015	185	263	
Sn20A	20	79.485	0.5	0.015	183	277	autobody
Sn20B	20	77.985	2	0.015	184	270	autobody dent filling
Sn15	15	84.485	0.5	0.015	225	290	coatings and joiningg metals
Sn10A	10	89.48	0.5	0.015	268	302	Automotive electronics
Sn10B	10	87.5	0.02	2.4	268	299	Automotive electronics
Sn5	5	94.48	0.5	0.015	308	312	Automotive Radiators
Sn2	2	97.48	0.5	0.015	316	322	Automotive Radiators

Table F.4Leaded Brass Compositions (ASTM)

Designation	**% Cu**	**% Zn**	**% Pb**
C33500	63.5	36.0	0.5
C34000	63.5	35.4	1.1
C34500	63.5	34.5	2.0
C35000	62.0	36.6	1.4
C35300	62.0	36.0	2.0
C35600	61.5	36.0	2.5

Table F.5: Self Diffusion of Pure Metals: FCC Structure

Metal	Melting Point °K	D (mm^2/s)	Q/RT
Pb	601	137	21.8
Al	933	170	18.3
Ag	1234	40	18.4
Au	1336	10.7	15.9
Cu	1356	31	17.8

Table F.6A Some Close-Packed Structures of Metals

Structure	Crystal Coordination Number	Atoms per unit cell	Unit cell vs atomic radius	Void %	Examples
Hexagonal closest packed (hcp)	12	2		25.96	Cd, Mg, Ti, Zn
Face-centered cubic (fcc)	12	4	$4r = s\sqrt{2}$	25.96	Al, Cu, Pb, Ag Ni
Body-centered cubic (bcc)	8	2	$4r = s\sqrt{3}$	31.98	Fe, K, Na, W

Table F.6BCommon Ionic Crystal Unit Cells

Structure	Unit cell	Coor. #	Sulfides	Ion	radii
sodium chloride	fcc	6	PbS	S^{2-}	170
cesium chloride	cubic	8	Ag_2S	Ag^+	142
zinc blende (ZnS)		4	Cu_2S	Pb^{2+}	133
wurtzite (ZnS)		4		Cu^+	74
fluorite CaF_2		8 cation, 4 anion			
rutile (TiO_2)		6 cation, 3 anion			

Table F.7: Enthalpy to Melt by Structure Type

Structure type	Metal	melting pt, K	Q/RT_m	D $\mu m^2/s$ at melting point
hcp	Cd	594	15.4	0.99
	Zn	692	15.9	1.6
	Mg	922	17.6	2.3
bcc	Rb	312	15.2	5.8
	K	337	14.6	15
	Na	371	14.2	16
	Li	454	14.7	9.9

Table F.8
Melting Points for Several Metal Mixtures: ºC

% 1st Metal	Cu+Sn	Cu+Pb	Sn+Pb	%2nd Metal
100	1084	1084	232	0
90	1005	1020	216	10
80	890	1005	200	20
70	755	985	185	30
60	725	985	190	40
50	680	950	220	50
40	630	945	240	60
30	580	925	262	70
20	530	920	276	80
10	440	870	295	90
0	232	325	326	100

Table F.9: Heat Capacity and Specific Gravity of Pure Lead

Specific Heat Capacity		Specific Gravity	
T (ºC)	s (J/g-ºC)	T (ºC)	d (g/cm^3)
0	0.12426	20	11.34
20	0.12803	327 (solid)	11.005
100	0.13388	327 (liquid)	10.686
327 (m.p.)	0.16317	650	10.302
500	0.15480	850	10.078

Solid Lead: face centered cubic, bond length Pb-Pb, at 25ºC, 349.9 ppm

Table F.10: Historical Recipes for Niello

Author	%Ag_2S	%Cu_2S	%PbS	Melt range, C
Pliny	53.4	46.6		700
Theophilus	55.7	30.3	14.0	430-560
Eraclius	32.3	35.2	32.5	440-460
Cellini	16.2	35.2	48.7	440-640
Eutectic	25	35	39	440

Table F.11: Contemporary Niello Composition

Niello Origin	Silver	Cu	Pb	Other	S
Augsberg	1	1	2		excess
Persian	1	5	7	ammonium chloride 5	24.5
Thailand	1	5	3		excess
Russian (Tula)	1.5	2.5	3.5		12
Bolas	2	4	1	antimony 1	excess
Wilson	6	2	1		10
Fike	6	2	2	borax 1-2	>10

Table F.12: Temperature Used in Glassmaking °C

Type of Glass	strain $10^{14.5}$ poise	Annealing 10^{13} poise	Softening $10^{7.5}$ poise
Silica glass	820	910	1500
Soda-lime silicate glass	505	548	730
Low lead silicate glass	395	430	626
High lead silicate glass	390	430	580

Table F.13: Yellow Glaze Recipes

Potter	Location	Date	Litharge		Sb	Pb	Sn
Lawrence Harrison	Liverpool	1707	9 lbs	6 lbs	Pb&Sn ashes (3)		
Benjamin Tomkinson	Liverpool	1820		3	3	3	
Thomas Lakin			1824	4	3		1.5

Table F.14: Lead Chromate Color Can be Tuned

Mineral	Color	% $PbCrO_4$	% $PbSO_4$	% $PbMoO_4$	Structure
Anglesite	white or colorless	0	100	0	orthorhombic
	Primrose	45	55	0	monoclinic
	Pale Primrose	65	35	0	orthorhombic
	Lemon	70	30	0	monoclinic
Crocoite	Middle Orange	100	0	0	monoclinic
	Scarlet	80	12	8	psuedo-tetragonal
				8-40	tetragonal lattice distortion
Wulfenite	Orange	0	0	100	tetragonal

Table F.15: Molar Refractive Index of oxides

Oxide	Name	Molar Refractive Index
SiO_2	quartz	7.18
	cristobalite	7.4
TiO_2	rutile	12.82
Al_2O_3	α form	10.7
	β form	11.3

Table F.16 on Effect of Modifiers on Molar Refraction

Group I Modifier	Group II Modifier	Molecular Density	refractive index, n	molar refractive index
Li (Li_2O)	$MgO-SiO_2$	2.421	1.552	41.80
	SrO-	2.815	1.565	43.32
	BaO	3.150	1.599	45.87
Na (Na_2O)	MgO	2.425	1.4995	41.45
	CaO	2.601	1.5340	42.79
	SrO	2.832	1.5400	44.99
	BaO	3.035	1.5735	49.42
K (K_2O)	MgO	2.401	1.4990	45.73
	CaO	2.466	1.5385	49.50
	SrO	2.740	1.5355	49.81
	BaO	3.011	1.5528	51.71

Table F.17: Refractive index, n, of metals

Group IIb	n_r	Group Ivb	n_r
Cadmium	0.82(liq)/1.13(solid)	Tin	2.1(liq)
Mercury	1.6(liq)	Lead	2.6(sol).

Table F.18: Lead Semi-conducting materials used as IR detectors

Compound	Form	cell Å,	cell vol. $10^{-24}cm^3$	Wavelength Range Absorbing
PbS	cubic	5.9360±0.005	209.16±0.05	0.8 to 3 μm
PbSe	cubic	6.1255±0.0005	229.84±0.06	1-6.5 μm
PbTe	cubic	6.4606±0.0005	269.66±0.06	1-6 μm
PbSnTe				5-13 μm
PbSnTe (cooled)				6.6-18μm

Table F.19: Development of Color and BandGaps

Spectral Region	Observed Color	Absorbed Color/λ, nm	λ in eV	Crystal with Bandgap	Type of Solid
Ultra-Violet	Colorless	98, none	12.65		
			12	NaF	Ionic Solid
			8.5	NaCl	
			7.5	NaBr	
		350, none	3.54	TiO_2	
Visible Light	Greenish-yellow	400, violet	3.09		
			2.91	CuBr	Semi- Conductors
	yellow	450, blue	2.75		
			2.7	ZnSe	
	red	490, b-green	2.53		
	violet	570, y-green	2.17		
	dark blue	580, yellow	2.13		
	blue	600, orange	2.06		
	green	650-700, red	1.9		
Near IR	Black	700-1000	1.77-1.24		
IR	Black	1-50μm	1.42	GaAs	
			0.66	Ge	
			0.41	PbS	
			0.0247		
			0	Metal	

Table F.20 Charge Transfer Pigments

Pigment	Mineral	Formula	Process
Cadmium Yellow	greenockite	CdS	$L_{\pi p} \rightarrow$ metal 5s
Vermillion	cinnabar	HgS	$L_{\pi p} \rightarrow$ metal 6s
Orpiment		AsS_3	
Massicot (yellow)	orthorhombic	PbO	$L_{\pi p} \rightarrow$ metal 6s
Litharge (red)	tetragonal	PbO	
Minium		Pb_3O_4	$Pb^{2+} \rightarrow Pb^{4+}$
Lead tin yellow I		Pb_2SnO_4	
Lead tin yellow II		$PbSn_{1-x}Si_xO_3$	
Naples yellow		$Pb_3(SbO_4)_2$	$L_{\pi p} \rightarrow$ metal 5s or 5p
		$Pb_2Sb_2O_7$	
Chrome yellow	crocoite	$PbCrO_4$	$L_{\pi p} \rightarrow$ metal 3d (Cr)
dark red	Phoenicocroite	$Pb_2O(CrO_4)$	$L \rightarrow M$
yellow	wulfenite	$PbMoO_4$	$L \rightarrow M$
Red and yellow ochres	hematite	Fe_2O_3	$L_{\pi p} \rightarrow$ metal 3d (Fe)
King's Yellow (opriment), Jeweler's rouge			
		Fe_3O_4	$Fe^{2+} \rightarrow Fe^{3+}$

Table F.21: Anticorrosive Paints

Name	Main Constituent	Density G/cm^3	Humidty	SaltSpray	SO_2
Alk.Pb	Pb_3O_4	2.239	5	4	5
Alk.P3	$ZnPO_4$ + Lots $BaSO_4$	1.502	2	5	0
Alk.P2	$ZnPO_4 + BaSO_4$	1.463	2	2-3	0
Alk.P1	$ZnPO_4$	1.370	1	2	0
Alk.Fe	Fe_2O_3	1.331	1	2	0
Alk.Cr	$(4ZnO.K_2O.4CrO_3.3H_2O)$	1.198	5	5	5

Table F.22: Lead Azide, compression

	Compressibility 10^{-6} bar^{-1}		
	1/ao	1/bo	1/co
$Ba(N_3)_2$ 0.71	1.22	0.58	
αPb	1.91	0.30	0.20
β Pb	2.34	1.51	0.57

Table F.23: Bond lengths in Azides

	N_1-N_2 (Å)	N_2-N_3 (Å)		N-N-N (deg)	impact sensitivity
$Cu(N_3)_2$	orthorhombic	1.199	1.146	176.7 (1.1)	highest
α Pb	orthorhombic	1.164	1.164	179.5 (6)	
Ba	monclinic	1.168	1.164	179.7 (2)	
K		1.186	1.186		Least

Table F.24 Lattice Energies of Azides

	U (kJ/mole)
Ca	2166
αPb	2162
Sr	2067
Ba	1962

Table F.25: Bandgap and Exciton Energies for Azides

Compound	Bandgap (eV)	Exciton (eV)
NaN_3	8.46	6.5
KN_3	8.55	6.5
Rb	8.82	6.6
Cs	8.61	6.3

Table F.26: Velocity of Expanding Gases From Lead Azide

density g/cm^3	velocity (km/s)
3.78	4.63
3.60	4.35
3.20	4.04

Table G.1: Soil Lead as a Function of Distance from A Smelter, ppm

Distance from stack in km	0-5.1 cm	5.1-10.2 cm	10.2-15.2 cm
0.2 (W)	8,700	840	1,815
0.5 (SSE)	2,573	138	128
0.8 (E)	2,742	205	235
1.4 (WSW)	375	68	65
2.4 (SE)	300	175	90

Table G.2 Soil Lead Near a Home (100 years old)

Distance (m)	Depth (Cm)	Side of House A	B	C
0-1	0-5	1050	44700	7330
	5-10	1060	20600	4680
	10-15	940	7270	3300
5	0-5	431	110	298
	5-10	404	2020	366
	10-15	400	2110	286
10	0-5	194	1940	730
	5-10	162	374	686
	10-15	248	2175	452

Table G.3 Correlation between lead based paint and soil:

	% within soil guidelines	% exceeding guidelines
No Lead Based Paint	94	6
Lead Based Paint, intact	79	21
Lead Based Paint, unintact	52	48
exterior Lead Based Paint	73	27

Table G.4 Dust/Soil Lead in Un-renovated homes

Site	Lead Content
window channel dust	2150 ug/g
air duct dust	875 ug/g
window stool dust	245
Foundation soil	109 ppm
floor dust	106
Entryway dust	96.3
Entryway soil	65
Boundary soil	53.6

Table G.5 Paint Materials and Characterization

Sample (mil)	XRF Pb mg/cm^2	total layers/lead layers	total thickness
Interior particle board for shelving	4.2-4.4	3/1	33-6
Exterior pine wood	3.8-4.0	4/1,2	5-7
Pine wood window frame	4.0	4/1,2	5-7
Exterior Steel	2.1-2.9	8/1,2,4	8-10
Aluminum soffit vents	2.5	2/1	3/5
Galvanized steel drip cap	2.2	2/1	2-5

Table G.6: Modeling Parameters for Equation 10.1.

Parameter		Range	Quality
C	Time spent outdoors (hrs/day)	2-4	good
	Volume of air respired (m^3/day)	4-5	good
	Natural lead of atmosphere (ug/day)	2.4	Fair
	Lead from solder (ug/day)	11.0	Fair
	Lead from drinking water (ug/day)	1.2	Poor
	Atmospheric lead in food (ug/day)	11.3	Fair
	Undetermined in f food mg/day	1.2	Fair
	dirt/dust (mg/day)	100	Poor
A	Deposition/absorption in lungs (%)	35-60	Fair
	Absorption in gut (%)	42-53	good
	dirt lead absorption (%)	30	good
T	Transformation	0.4	good

Table G.7: Correlation between predicted and observed blood lead

Site	Soil ppm	Indoor Lead ppm	Predicted Dust µg Pb/dL	Observed µg Pb/dL	Ratio predicted/observed
East Helena	720	1588	15	14	1.1
Herculaneum	183	1030	19	19	1.0
Toronto 1974-1975	5000	5000	41	35	1.2
Toronto 1984-1985	1800	1800	17	16.5	1.1
Kellogg	3474	3933	31	21	1.5

Table G.8. Sources of Lead Uptake by Children

Source	Level in Source	Total Intake	Absorbed	Lead uptake
Air (urban)	0.5 ug/m^3	3.3 ug/day	40%	1.3 ug/day
Water	20 ug/L	20 ug/day	50%	10 ug/day
Food	0.1 ug/g	100 ug/day	50%	50 ug/day
Dust	500-2400 ug/g	20-500 ug/day mean		100

Table G.9 Allowable Limits for Lead

Daily source	Normal Exposure
Food/Beverages	100 ug/day (HHS)
Drinking Water	<15 ug/L (1985)
Air	150 ug/m^3/8 hr (ACGIH
	50ug/m^3/8 hr (OSHA)
Abated Dust	floors: 200 ug/ft^2 (HUD)
	Sills 500 ug/ft^2 (HUD)
Uncontam. Paint	<0.06% (HHS)
Uncontam. Soil	10-50 ug/g = 10-50 ppm
contaminated soil	>50-100 ppm
action level soil	>500 ppm

Table:G.10: Andrew Jackson's Hair

Hair Sample	**Concentration in parts per million (ppm)**	
	Mercury	**Lead**
1815	6.0	156
	6.0	105
1839	not detected	68
	5.6	70
normal range	0.01-1.2	0.002-20

Table G.11: Amount of Lead on Children's Hands

Location	Mean/Median	range	comments
Belgium		20-436 ug/hand	near a smelter
Connectict	2400 ug/g	650-4100 ug/g	used sticky tape
London		12-43 ug/child	city schools
Rochester	5 ug/towel	<5-20 ug/towel	suburbs
	20 ug/towel	<5-15 ug/towel	city
	49 ug/sample		High blood lead group
	21 ug/sample		Low blood lead group
USA, Belgium		5-142 ug/hand	

Table G.12: Blood Lead concentration in towns with Pottery works in Mexico

	µg/100 mL	
Age	Lead Glaze producing town	Non-lead glaze workers
0-9	81	19.5
10-19	48.9	20.7
20-29	51.2	23.3
30-39	52.8	21.3
40-49	56.2	22.8
50-59	57.8	20.2
60-69	69	13.7
>70	56.6	19.5

G.13 **Percentage of homes**

	Paint lead concentration (mg/cm^2)			
Location	>0.7	>1.0	>1.2	>2.0
Interior				
1960-1979	60	41	28	7
1940-1959	70	59	44	20
before 1940	73	60	57	50
Exterior				
1960-1979	55	42	31	12
1940-1959	82	76	69	46
before 1940	83	79	69	66

Table H.1: Allowed Metal Content in Sewage Sludges

	USEPA Regulatory Limit (1993)
Federal Register, Vol. 58,, 32, Feb. 19, 1993.	
Ceiling Limits to land apply	840 mg/dry kg
Concentration limit to land apply	
monthly average concentration	300 mg/dry kg
Annual Loading rate	15 kg/ha-yr
Cumulative loading	300 kg/ha

Table H.2: US Production of Waste 1991

Material	Million tons/year
Municipal Solid Waste	180
Industrial Hazardous Waste	250
Organic Waste	3.6
Medical Waste	4.8
Sewage Sludge	10.4
Total	10^{12} lbs/year

Table H.3: Common Components of Municipal Wastes

Material	Bache Weight%	Bagghi Weight%	Sullivan and Makar Weight%	Law and Gordon Recoverable Weight %
paper	50.2	41.6-53.5	51.7	
Yard	17.8	12.5-24.2		
Food	16.8	4.4-15.3 4.4		
Glass		6.5-10.9 10.5	30	
Plastics	5.2	0.76-5.7 5.0		
Wood	4.6		2.6	
Leather/rubber	3.4		0.7	
Textiles	2		1.8	
Fine glass, grit, dirt			10	
iron metals			7.6	15
corrugated board		3.5		
aluminum			1.1	1.75
Zinc & copper			0.2	0.75
Slag				25
fine ash				22.5

Table H.4: Lead Speciation Under Anaerobic Conditions (Landfilling)

	Acid Phase	Methane Phase
Sulfate, mg/L	1500	140
Sulfide, mg/L	Not Detectable	0.3
Lead, mg/	6.8	Not Detectable

Table H.5: Energy of Different Waste Streams

Material	GigaJoule/Ton	%National Need
Coal	26-29	
Industrial Waste	16	2-3 European Community
MSW (Municipal Solid Waste)	10	5, Netherlands 5-10 Germany
Scrap Tires	32	
Dry Sewage	~32	
Total Waste		10 England

Table H.6 Metals in Chicago Sewage Ash

Elements acid digestable (nitric-perchloric acid)		Sewage-sludge incinerator ash	Triple-superphosphate
Aluminum		63.8 g/kg	8.3 g/kg
Calcium		91.4	145.7
Iron		40.5	15.6
Magnesium		18.6	3.7
Phosphorus		74	213.6
Potassium		4.8	2.4
Sodium		2.6	16.6
Sulfur		3.3	ND
	ceiling conditions EPA (1993)mg/kg	mg/kg	mg/kg
Barium	-	1736	ND
Boron	_	42	44
Cadmium	85	128	7
Chromium	3000	1888	78
Copper	4300	3846	7
Lead	850	710	39
Manganese	_	2353	294
Molybdenum	75	45	ND
Nickel	420	530	29
Zinc	7500	7213	79

source: Bierman et al. J. Env. Qual, 1994, 23, 822

Table. H.7:

Material	Total Ash Produced	Incinerator output of Lead	%
Bottom ash	108 ±25.2kg/t	666±336 mg/kg	59.4
Electrostatically Precipitated ash	35±7.1 kg/t	1320±449 mg/kg	38.1
Ash quenching water	0.223±0.014 m3/t	1.4±0.17 mg/mL	
Scrubber water	_	_	
Exhaust gas	7480±965m^{3}N/t	0.47±0.3 mg/m^{3}N	2.5
Total amount g/t			121.6

Source: Nakamura et. Al. Waste Management, 1996, 16, 516, 509-517.

Table H.8: Distribution of Lead in Incinerator Ashes

Material	Law and Gordon	Davison	Reimann	Brunner
Bottom Ash	110			0.89 g/kg
Fly Ash	140	3870	7%	25g/kg
Scrubbed Ash	370	8450	93%	6.2 g/kg
emitted particles	620		<1%	1.4g/m^3

Table H.9 Lead Leaching From Incinerator Ash

Time	mg Pb/L
1 min	13
30 min	13
5 h	15
9 h	17
24 h	7
48h	8

source Belevi, Waste Management Research: 1992, 10, 153-167.

Table H.10: Silica Terminology

Term	NMR	Mineral	Kg, cal Heat of Formation
Nesosilicate		Olivine	18,852
Silanetriol	Q^1		
Sorosilicate		Melilite	21,511
Singe Chain	pyroxenes	Diopside	
Cyclosilicate		Beryl, Tourmaline	
Silanediol	Q^2		
Inosilicate	Amphibole	Hornblende	27,290
Silanol	Q^3		
Phyllosilicate Sheet		Kaolin	29,981
Tectosilicate			
Siloxanes	Q^4	Quartz	37,320

Table H.11: Reactions and Solubilities of Silicates and Alumintes

Reaction	LogK
SiO_2(amorphous) + $2H_2O \rightleftharpoons H_4SiO_4$	-2.7
SiO_2(quartz) + $2H_2O \rightleftharpoons Si(OH)_4$	-3.7
$Si(OH)_4 \rightleftharpoons SiO(OH)_3$- + H^+	-9.46
$Al_2Si_2O_5(OH)_4$(kaolinite) + $5H_2O \rightleftharpoons Al_2O_3{\cdot}3H_2P$(gibbsite) + $2H_4SiO_4$	-9.4
½ $Al_2O_3{\cdot}3H_2O \rightleftharpoons Al^{3+} + 3OH$	-34
½ $Al_2Si_2O_5(OH)_4$ + 1/$2H_2O$ + OH- $\rightleftharpoons H_4SiO_4$ + 3OH-	-38.7

Table H.12: Cement Clinker Composition

Mineral	Chemical Name	Chem. Comp.	Clinker Acronym	Wt%
Alite	tricalcium silicate	Ca_3SiO_4	C_3S	50-70
β-Belite	dicalcium silicate	Ca_2SiO_4	C_2S	15-30
Aluminate	tricalcium aluminate	$Ca_3Al_2O_6$	C_3A	5-10
Ferrite	tetracalcium aluminoferrite		C_4AF	5-15
Lime	calcium oxide	CaO	CaO	1
Gypsum	calcium sulfate	$CaSO_4$		

Table H.13: Some Minerals Found in Set Cement

Mineral Name	Chemical Forumula	Density g/cm^3
Tobermoite	$Ca_5Si_6O_{17}\cdot 5H_2O$	2.42
Jennite	$Na_2Ca_5(SiO_3)_3Si_2O_7(OH)_6\cdot 3H_2O$	2.32
Ettringite	$[Ca_3(Al(OH)_6\cdot 12H_2O]_2(SO_4)_3\cdot 2H_2O$	1.77

Table I.1: Imports of Lead Pigment to U.S.
Haynes, Vol. 1

	White		Red		Total	
Year	Short Ton	$	Short Ton	$	Short Ton	$
1821					3,978,649	
1831					111,178	6,762
1841					532,122	31,617
1851					1,105,852	52,631
1857					1,793,377	113,075
1858	977,323	58,774	808,528	50,652		
1861	1,467,949	93,036	736,423	41,518		
1872	7.033,499	415,589	1,295,616	78,411		
1881	1,048,622	59,082	212,423	10,009		
1891	628,414	43,041	519,613	20,950		
1901	379,388	21,993	524,935	23,933		
1911	659,915	38,878	1,035,254	40,225		

Haynes, Vol. 1, p. 413

Table I.2: Production in the U.S.
(Haynes, American Chemical Industry, Vol. 1, p. 406)

	White Lead		Zinc Oxide	
Year	Short tons	$	Short tons	$
1810	369			
1830	3,000			
1840	5,000			
1850	9,000	$5,242,213		
1860	15,000	$5,380,347		226,860
1870	35,000			
1880	61,739	$8,770,699	10,061	766,337
1890			8,824	695,920
1900	58,051	$4,211,181		
1910	43,617	$3,921,803		

Table I.3 (Thompson and Haynes)

Domestic Lead Production						Imported Lead
Date	Source	pounds	Total Silverless Ore	Silver Ore	Total	
1825			1,500		1,500	
1830			8,000		8,000	
1835			13,000		13,000	
1840			17,000		17,000	
1845			30,000		30,000	
1850			22,000		22,000	
1855			15,800		15,800	
1860			15,600		15,600	
1865			14,700		14,700	
1867	St. Joe, Mo. Enters production				17,000	40,000 pounds
	Smelters in Helena, Mon, and Nev. Open					
1870			17,830		17,830	
1873	Utah	15,000				
1875			24,731	34,909	59,640	
1877	Utah	27,000				
1878	Leadville, Co. goes into production (6-20 oz Ag/ton)					
1880			27,690	70,135	97,825	
1885			21,975	107,437	129,412	
1890			31,351	130,403	161,754	$657,658
1891						$2,560,885
1892			31,678	181,584	213,262	$3,653,378
1893						$5,792,624
1894			37,686	121,645	159,331	$6,679,171

Table I.4: Lead Soap Production
Lead Naphthenate

Date	Production (Metric Tons)	Shipments (Metric Tons)	Value $ (U.S.) Thousand
1958	4,110	3,697	2,419
1959	4,266	3,794	2,595
1960	3,740	3,302	2,209
1961	3,224	2,769	1,754
1962	3,671	3,366	2,079
1963	4,222	3,858	2,059
1964	5,53	5,581	2,709
1965	5,804	4,996	2,602
1966	6,471	5,725	2,841
1967	6,604	5,551	2,876

Table I.5: Chrome Yellow Consumption, U.S.

Year	Production thousand metric tons	Shipment thousand metric tons	Value $(U.S) million
1962	22.2	21.6	15.1
1963	22.4	22.2	15.0
1964	24.0	24.0	17.0
1965	26.5	25.0	18.7
1966	28.5	28.2	21.5
1967	27.9	27.0	20.5
1968	29.8	29.0	22.5
1970	29.4	28.8	23.9
1971	18.1	25.7	22.1

Table I.6
Estimated Lbs White Lead/Housing Unit

1914-23	110
1920-29	87
1930-39	42
1940-49	22
1950-59	7
1960-69	3
1970-79	1

Table I.7 Gasoline Sales

Date	Event
1935	$37x10^3$ tons of leaded gasoline sold in US
1944	$75x10^3$ tons leaded gasoline sold in US
1955	$165x10^3$ tons of leaded gasoline sold in US
1965	$225x10^3$ tons of leaded gasoline sold in US
1970	$279x10^3$ tons of leaded gasoline sold in US
1975	$175x10^3$ tons of leaded gasoline sold in US

<u>Timeline J.1: Metals in Mesopotamia</u>
Bold Indicates First Appearance

Year	**Event**	**Duration**
50,000 B.C.	Stones, hunters & gatherers	
30,000 B.C.	Fired clay figures (Czechoslovakia)	44,000 years
6000	Persia, Palestine: Cereals	
5300	Native **Gold** and **Copper** Ornaments	
5000	Bone sickles with inset flint teeth	2000 years
4500	Pottery	
4000	Fired Pottery (Jericho)	
3800	Smelted **copper**	
3500	**Lead** known	
3100	**Tumblers of lead in graves**	1800 years
2650	**Tin** as a separate element known	
2500	Pure **silver** objects (from lead+silver ore)	
2500	Accidental iron objects	
2400	Copper + tin impurities = Sumerian bronze. Trade routes established to Saxon Tin mines	
2100	SnO found in Lesbos	
2000	True bronzes	
1800	Bronze arts and swords	
1600	Tin smelting	600 years
1377	**Iron** dagger for Amenhotep III	
1200	Iron at Troy, not accidental	
700	Iron tools in Egypt	
200 B.C.	**Mercury** known as pure element	
50-200 A.D.	**Brass** (Cu + $ZnCO_3$)	
1789	**Titanium** discovered	3000 years
1907	Bakelite **Polymer** manufacturing = Plastics	

Timeline J.2: Biological and Ore Evolution
Material in bold indicate important events in the evolution of lead ores

Years Ago	Geologic Age	Event
15,000,000,000	Origin of Universe	Big Bang
4,500,000,000-3,500,000,000	Planetary Formation	Earth condenses
4,000,000,000		First life on Earth
3,500,000,000		Oldest dated rocks
3,500,000,000 to 2,500,000,000	Archaean or early Pre-Cambrian	
3,500,000,000-570,000,000	Pre-Cambrian	Single continent present
2,000,000,000		Complex single cells
1,800,000,000		Free oxygen in atmosphere
		Broken Hill Lead Ores
570,.000,000-225,000,000	Paleozoic	Life in sea
570-500,000,000	Cambrian	Life emerges to land
500-430,000,000	Ordovician	
430-395,000,000	Silurian	**Howard's Pass, Canada, Lead ore**
395-345,000,000	Devonian	**Meggen, Germany Lead ore**
345-280,000,000	Carboniferous (Mississippian/Pennsylvanian)	**Coral beds, Ireland, Navan Mines**
280-225,000,000	Permian	
225,000,000		Life decimated by catastrophic event
225,000,000	Mesozoic	
225,000,000-190,000,000	Triassic	First dinosaurs
190,000,000-136,000,000	Jurassic	Brontosaurus
180,000,000		Pangaea splits
136,000,000-65,000,000	Cretaceous	Pteranodan
65,000,000		Giant meteor impact on yucatan
		Lasted 45 minutes; 90% of life decimated
65,000,000	Cenozoic	
65,000,000-2,000,000	Tertiary	
55,000,000		First primates evolve
		Laurasia split into North America/Eurasia
		Gondwana split into South America/Africa
		(Nigerian lead ores)
40,000,000		First monkeys
30,000,000		North and South America join
		Andes, Rockies develop
23,000,000		First apes
5,000,000--present	Quaternary	Development of hominids (Australopithecines)
3,000,000		*Homo habilis*
2,400,000-1,500,000		*Homo erectus*
~2,000,000		First use of fire
~400,000		*Homo sapiens* (another large brain increase)
~10,000		Humans Leave Africa
10,000		Ice Age
~5,500		Lead discovered

Table J.3: Timeline for South and Middle America

Time	Location	Group	Event
10,000 B.C.	Migration to New World		
3500 B.C.	Andes and Amazonia		Potato, manioc, llama, guinea pig domesticated
3500 B.C.	Mesoamerica		Corn, beans, squash turkry domesticated
1500 B.C.	Peru/Chili	Chavin, Paraca	Copper/Tin co-melting
1455-569 B.C.	Valley of Mexico	Tlatilco+ Zacateno	
493 B.C.	Valley of Mexico	Teotihuacan	
800-100 B.C.	Yucatan	Mayan, Miraflores	
200 B.C.	Colombia	Moche/Tolima	Copper/Gold casting
100-300 A.D.	Late Paraca		
850 A.D.	Peru/Chili	Alloys	
1200 A.D.	Mexico		Importation of Cu/Sn/Ag alloy technology

Timeline J.4: South Coast of West Africa

Time	Location	Event or Person
800 B.C.-200 A.D.	Bauchi Plateau, Nigeria	Nok Culture at height
800 A.D.	Igbo-Ukwu, Nigeria	
900-1000 A.D.	Ife, Nigeria	Yoruba Culture at height
1300 A.D.	City of Benin	Edo people
1440-75	Benin	King Euware
1440	Portugal	First European nation imports African slaves for labor
1480-1540	Benin	King Ozolua establishes diplomatic ties with Portugal and trades in ivory, pepper, Palm oil, and slaves.

Timeline J.5: Chinese Timeline

Date	Period	Event	%Lead
7500 B.C.	Neolithic	rice, millet, pig, silkworm domesticated	
5000-1700 B.C.	Neolithic		
1766-1111 B.C.	Shang		7.2%
1100 B.C.	Late Shang/Early Chou		4.2%
950 B.C.	Middle Chou		12%
1050-950 B.C.	WesternChou (Zhou)		21.5%
771-481 B.C.	Eastern Chou (Zhou) Spring and Autumn Period		
481-221 B.C.	Warring States		
221-206 B.C.	Qin Dynasty,	1st Yellow Emporer (Shi Huangdi of Qin), starts Great Wall	
206 B.C.- 8 A.D.		Huns, nomadic Asians of Turkish, Tatric and Uguan origin spread across the Caspian Steppes. Split under pressure from Mongols. 50,000 families move south to western China. Remainder move west and northwest to Volga/Don Rivers	
138 B.C.		Emporer Han Wudi sends General Zhang Qian sent west to make allies against the Huns (The SILK ROAD).	
100 A.D.		Buddhism moves across silk road to China	
219-580 A.D.	Northern and Southern Dynasty		
618-906 A.D.	T'ang Dynasty	Nestorian Christians, Islamic Arabs, emissisaries from Japan and Persia.	
907-960 A.D.	Five Dynasties (Civil War)		
960-1270 A.D.	Song (Sung) Dynasty		
1260-1368 A.D.	Yuan Dynasty of Mongol Genghis Khan, court described by Marco Polo		
1368-1644 A.D.	Ming Dynasty		

Timeline J.6: Timeline of Events in England

Date	Event
410 A.D.	Roman withdrawal
450	Saxon mercenaries hired by remaining romans to guard against Picts/Scots. Warlords take over
400-600	Migration Period of Europe
600s	Polytheistic German Kingdoms of Northumbria, Bernicia, Dera, Lindsay, Mercia, East Anglia, Essex, Wessex, Sussex, Kent
596	Gregory I sends Augustine to Kent where King Ethelbert is converted
	Augustine becomes first Archbishop of Canterbery
612-671	Northumbria's King Oswy choses Roman Christians over Irish missionaries
	Confluence of mediterrean scholars and northumbria produces a flowering of scholarship
700s	Predominant Kingdom is that of Mercia
800	Charlemagne, Emperor of "Germany"
800s	Egbert of Essex is predominate. His grandson is Alfred the Great.
871-997	King of the West Saxons, Alfred the Great. Made peace with Danes, defeats returning Danes in 878 (creates Danelaw). After 14 years of internal politics (capture of London) becomes King of unified England. Athelstan son of Alfred wields enough power to exact tribute from the Danes, only European country to do so. Patron of scholarship and invites foreign scholars, including Welsh monk Asser (885-909) and Irish philosopher and theologian John Scotus Erigena.
	Ethelred II, the unready, tries to kill all asslmilated Danes provoking intervention of King Sweyn of Denmark who places his own son Canute II over England
	Edmund, son of Ethelred becomes king, is overthrown by Harold Harefoot, of Normandy.
1066	Invasion of the Normans

Timeline J.7: Timeline for Mesopotamia

Time	Events
4000 B.C.	Sumerian settlements
3800	Semites arrive
- - - - - - - -Historical Record Begins - - - - - - - -	
2360-2230 B.C.	Empire of Agade
2112-2004 B.C.	III Ur Empire, Timple of Nippur constructed
1792-1750	Hammurabis
1700-600	Babylonia
1125-1103	Nebuchadnezzar
--------------------------------DARK AGES----------------------------------	
721-705	Sagor Assyrian
668-627	Ashurbanipal, Assyrian King, Library at Nineva
600-529 B.C.	Cyrus of Media
546	Cyrus captures Lydia
539	Babylonia defeated by Cyrus the Great
558-486	Darius I, King of Persia
521	Darius captures Babylon
519-465	Xerxes I, King of Persia, invades Greece
323	Alexander the Great of Macedonia invades General is Ptolomy
250 B.C.	Parthia, City of Seleucia = Seleucids, empire from Euphrates to Indus River, Oxus to India Ocean (derivative of the Parthian shot, a first time that archers manuever on horseback to shoot backwards)

Timeline J.8: Timeline for Egypt

Date	Event
60,000 B.C.	Nile begins periodic flooding
7000-5500	Predynastic, Northern Cities
4000	Chalcolithic (copper) age
3200	Gerzean Period, development of hieroglyphic writing
3100	End of 0th dynasty
3100-2755	1st and 2nd dynasty (17 kings)
2686-2181	Old Kingdom (Memphis is capital)
2737-2717	3rd Dynasty, architect Imhotep (Step Pyramid)
2680	4th dynasty (Cheops)
To-2260	5th and 6th dynasties gradually decline
2260	1st Intermediate Period of 7-10th dynasties, in which Egypt is split
2134-1668	Middle Kingdom, reunification
	11th dynasty Mentuhotep II, capital at Thebes
	12th dynasty Amenemhet I
1668-1570	2nd intermediate period
	13th dynasty (65 kings!) invaders from Palestine cause loss
of	Nubia
	15th -17th dynasty, country is split
1570-1070	New Kingdom,
	18th dynasty Ahmose I of Thebes reunites country
1551-1524	Amenhotep I expands empire to Palestine
	Thutmose I first tomb in the Valley of the Kings
	Thutmose II
	Thutmose III
1453-1419	Amenhotep II
	Thutmose IV
1386-1349	Amenhotep III: Art and Architecture flourish
	Amenhotep IV (son-in-law is Tutankhamen)
	19th dynasty (Ramses I)
	Ramses II
	20th dynasty (Ramses III)
------------------DARK AGES--------------	
1070-671	3rd Intermediate Period
	21-24th dynasty, priests and northern kings vie for power
	25th (Nubian) dynasty
671 B.C.	Assyrians conquer
367-283	Ptolemy (Alexander's General)
51	Cleopatra (sister of Ptloemy XV
30 B.C.	Romans conquer

Timeline J.9 Timeline of Events in the "Classical" World

Date		Event
3000 B.C.	Minoan Civilization on Crete	
1600-1100	Height of Minoan civilization	
1200 B.C.	Mycenaen civilization rises, Minoan (Crete) decays	
1193-1184	Conquest and destruction of Troy	
1100-750	Homeric Age in Greece	
------ - - - - - - - - -DARK AGES- - - - - - - - -		
1100 B.C.	Carthage (North Africa across from Sicily) founded by Phoenicians	
10th century		Phoenicians (Lebanon), main city is Tyre
657	Greeks found Byzantium	
600-500		Etruscans rule Italy
510	Democracy established in Athens	
509		Roman treaty with Carthage (North Africa)
490	Darius (Persia) defeated by Greeks at Marathon/Greece	
481	Xerxes (Persia) destroys Athens	
		Rome defeats Carthage
479	Persian fleet destroyed	
477	Sparta assumes control of the war	
461	Pericles lived	
457-455	Sparta wars with Athens	
446-404	Peloponesian Wars	
387	Greek Asian cities pay tribute to Persia	
334	Alexander of Macedonia invades Persia	
335	Alexander the Great (Macedonia) conquers Greeks	
332	Egypt conquered by Alexander	
327	Alexander invades India	
232	Ptolemy I, Alexander's general, restores independence of Egypt	
266		Rome rules all of Italy
219		Hannibal crosses the Alps
206		Carthaginians driven out of Spain
146	Greece becomes Roman province	
133		Spain becomes a Roman province
55		Ceaser conquers England
47 B.C.		Ceaser conquers Egypt

Timeline J.10: Events in Spain

Date	Event
48?	Rome defeats Carthage
206 B.C.	Carthaginians driven out of Spain by Romans
206-409 A.D.	Spain a Roman province. Active working of the Rio Tinto silver mines.
409 A.D.	Visigoths on the move
	Library of Alexandria absorbed by the Islamic world
570-632	Mohammed
711	Berber army under Tariq ibn-Ziyad (died 720) crosses Gilbralter and defeats Roderick last of Visigoth Kings.
711-714	Moors (from Morrocco = Mauretania of Rome) conquer Spain
	Ommiad dynasty established
718-37	Pelayo, Visigoth chieftan rules Asturia, his son-in-law conquers Galicia
to	become King of Leon and Asturia.
	Arabs Rule from N. Africa by emirship, eventually a caliphate is set at Cordoba.
905-25	Independent, Christian kingdom of Navarre under Sancho I
970-1035	Sancho III captures parts of Muslim Aragon
1027-31	Fall of the dynasty of Hisham III, Muslim
1035	Ferdinand takes Moorish Galicia, declares himself emperor of Spain.
1212	Toledo conquered by Christians, Moors restricted to ports around Cadiz and Kingdom of Granada
1469	Ferdinand II of Aragon marries Isabella Queen Castille
1492	Columbus sent off
1512	All of Spain united under Ferdinand
1521	Conquest of Mexico

Table J.11: Alchemy

Date	Book	Type	Location/Author
	Cuneform Tablets		Mesopotamia: Babylon
1000 B.C.	Six Receipts of Ch'in	Metallurgy	Chinese
	Leyden X		Alexandrian Greek Papyri
384 B.C.		Chemical Theory	Aristotle
300 B.C.	Chapter of Powerful Nation	Metallurgy	Chinese
50-41 B.C.	De Architectura	Architecture/Materials	Vitruvias, Roman
23-79 A.D.	Historia Naturalis	Commentary	Pliny, Roman
100 A.D.	De Materia Medici		Pedanius Dioscorides
100-300 A.D.		**Peak Production of Rio Tinto Silver Mines**	
300 A.D.		Chemistry/Distillation	School founded in Alexandria
500 A.D.	Arthasatra	Sugar/Mining	Indian Treatise
500 A.D.	Buddhagosa, Discourse on Moral Consciousness		Indian Treatise
721 A.D.		As, S, and Hg Salts	Abu Musa Jabir ibn Hayyan (Geber)
700-800 A.D.	Compoistiones Variae	Compilations	Lucca Codex 190, Italy
700-800 A.D.	Mappae Clavicula	Compilations	Lake Constance Monastery
850-859 A.D.	Classified Essentials of the Tao of the True Origins of Things		Cheng Yin
880-909 A.D.	De Aluminibis et Salibus	Medical/Chemical	Ar-razi (Rhazes), Persia
980-1036 A.D.	Canon, De Anima	Alchemy/Medicine	Avicenna
1025 A.D.	On Bookbinding		Al-Muizz ibn Badis
	De Coloribus et Artibus Romanorum		Eraclius
1144 A.D.	Book of the Composition of Alchemy		Robert of Chester
1100s A.D.	De Diversis Artibis	Experimental Compilations	Theophilus
1250 A.D.	Speculum Naturale, Speculum Majus	Encyclopedia	Vincent of Beauvais
1214-1292 A.D.	Opus Majus	Gunpowder described	Roger Bacon
1234-1315 A.D.	De Secretis Natural sive Quinta Essentia		Raymond Lull
1260 A.D.	De Metallicus Et Mineralibus		Albertus Magnus
1300 A.D.	A Lexicon of Alchemy		Martin Ruland the Elder
1317 A.D.		**Pope John XII bans alchemy**	
1330 A.D.	De Investigatione Perfectionis		False Geber
	Summa Perfectionis Magisterii		
	De Inventione Veritatis		
	Liber Fornacum		
1330 A.D.	Physicus	Intro. To Arts of Alchemy	Petrus Bonus
1335. A.D.		**Barcelona Friars studying alchemy are excommunicated**	
1380 A.D.		**King of France Bans Alchemy**	
1395-1415		**European Economic Crisis Peaked**	
1431 A.D.	Le Begue		
1400s A.D.	Bolognese Manuscribt		
1437 A.D.	The Craftsman's Handbook	Lab Book	Cennino Cennini
1480-1538 A.D.	De la Pirotechnia	Lab Book	Vanoccio Biringuccio
1493-1541 A.D.	Probierbuchlein	Metallurgy	Paracelsus (Theophrastus von Hohenheim)
1494-1555A.D.	De Re Metallica	Metallurgy	Agricola (George Bauer)
1509 A.D.			Bernard Palissy
1552-1600s		**The Alchemist Emperor Rudolf**	
1568 A.D.	Duetrattati, uno torn alle otto principali arti del l'oreficeria		Cellini Benvenuto
1524-1579 A.D.	Li tre libri dell'arte del vasio		Cipriano Michele di Piccolpasso
1612	Arts Vetraria	Lab Book	Antonio Neri
1661	Natural Philosophy of Metals	Economic Theory+Alchemy	Johan Becher

Table J.12: Timeline for Paper

Date	Event
140-131 B.C.	Chinese make paper for packaging material
110-119A.D.	Chinese paper is usedfor printing
600-609	Chinese use wood block printing
632	Prophet Mohammed dies
625-650	Hellenistic city of Alexandria (site of first chemical school) captured by Islams
748	First newspaper (Chinese
751	Kao Hsien-chih defeated in Samarkand. Paper manufacturing transferred to Islamic world through capture of chinese papermakers
987/8	al-Muqaddasi receives 2 dinars for bookbinding in Yemen
	Library at Cordova contains 250,000 books
1025	Mu izz ibn Badis: treatise on bookbinding "Book of the Staff of the Scribes and Implements of the Discerning with a Description of the Line, the Pens, Soot Inks, Liq, Gall Kinks, Dyeing, and Details of Bookbinding."
1041-1048	Pi Sheng invents the movable type
1068	Library of Fatimids in Cairo sacked
1096	First Crusade
	Mongols sack library of Abbasids in Baghdad
1107	Colored printing used by Chinese to prevent counterfeiting
1109	Earliest sample of European paper.
1276	Paper mill established in Montefano
1391	Paper mill established in Nuremberg
1420-1429	Ink chemistry established by printer Peter Schoeffer who begins printing with colored inks in Europe
1435	Fall of Constantiople (and its library) to the Turks
1440	Johann Gutenberg invents the movable type in Europe
1494	Paper mill established in England

Table J.13: Time Line for Lead Based Yellows

Date	Location	Object	Pigment	
1500 B.C.	Tell al-Rimah	Glass	$Pb_2Sb_2O_7$	Lead Antimonate/Naples Yellow
1450-1350 B.C.	Nuzi	Glass		
1000-850 B.C.	Hasanlu	Glass		
600	Nimrud	Glass		
300-200	Rhodes	Glass		
140-260A.D.	Caerleon	Glass		
200-300	Sardis	Glass		
300-500	Kenchreai	Glass		$PbSnO_3$ Lead Tin Yellow II
300-400	Shavei Zion	Glass		$PbSnO_3$
<1300 A.D.	Europe	Paints		Orpiment
<1300	Europe	Paints	PbO	Massicot
1300-1650	Europe	Paints	$PbSn_{1-x}Si_xO_3$	Lead Tin YellowII/Venetian Yellow
1450-1750	Europe	Paints	Pb_2SnO_4	Lead Tin Yellow I/ Gial'lolino
1700-1850	Europe	Paints Glazes	$Pb_2Sb_2O_7$	Lead Antimonate/Naples Yellow
>1804	Europe	Paints	$PrCrO_4$	Chrome Yellow
			$PbCrO_4$-$PbSO_4$	Light fast chrome yellow

Table J.14: Events of the Reformation	
Christianity established in Roman Empire	324 A.D.
Division of Roman Empire into East and West	364
"re-establishment" of Western Empire; Holy Roman Empire	
Charlemagne Crowned Emporer	800
First Crusade	1096
Invention of the Western printing press	1450
Fall of Contstantiople to the Turks	1453
Explusion of the Jews From Spain	1491
Columbus	1492
Luther pens his Diatribe against Rome	1517
Conquest of Mexico by Catholic Spain	1519-1521
(Economic instability as Gold/silver flood Europe)	
Henry VIII declares himself head of Anglican Church	1531
Massacre of the Hugenots (Protestants) in France	1572
Galileo	1564-1642
Elizabeth I, Queen of England	1558-1603
Spanish campaigns in the Holland Lowlands	1566-1579
Spanish Armada	1588
Emporer Rudolf II of Holy RomanEmpire, Prague	1587
An alchemist, himself	
Explusion of the Muslims From Spain	1609
30 years War	1618-1648
Mayflower (Puritans and Hugenots)	1620
English Civil War (Cromwell)	1642
Becher Publishes First Alchemy Book	1656
In Emporer Ferdinand III's court, Vienna	
English Restoration of Monarchy, Charles II	1660

Timeline J.15

Time line for Roman Republic and Empire

Date	Event		
509 B.C.	Tarquins expelled from Rome		
480	Carthaginians defeated		
390	Rome destroyed by Gauls		
376-367	Patricians/Plebes war, granted equal rights.		
348	Treaty with Carthage		
312	War with Etruscans		
		~300	First Silver Coinage
281-275	Pyrrhic War		
266	Rome mistress of all Italy		
264-241	First Punic War		
225	Gauls repulsed in Italy		
219	Hannibal crosses the Alps		
		~212	Introduction of Denarius
206	Carthaginians driven out of Spain		
146	Conquest of Carthage, Greece, sack of Corinth		
		~141	Denarius retariffed
83-82	Sulla Civil War		No bronze minted in Rome
64	Syria becomes a Roman province		
58-49	Caesar's Gallic command		Romano-Syrian tetradachms
49	Ceasar dictator		
		~46	Start of regular gold coinage
43	Second oligargy (Octavius Caesar, Mark Antony, Lepidu)		
42	Defeat of Brutus and Cassius		
		38-31	Debasement of Anthony's silver
36	Defeat of Pompey		
31	Defeat of Anthony and Cleopatra		
31BC-14AD	Octavian (Augustus)	~23	Reform of bronze coinage
19-14	Conquest of Spain completed, Austria added to Empire		
6 A.D.	Romans abandon Germany	~5 B.C.	Reform of silver/bronze at Antioch
37	Caligula emperor		
41	Claudius emperor	~40	End of Civic coinage in west
47	Rome conquers Britain		
54-68	Nero emperor	64	Nero's reforms and debasements
64	Nero sets fire to Rome		
68-117	8 emperors		
79	Vesuvius erupts, Titus		
98-117	Trajan	~107	Debasement and withdrawal of earlier silver
117	Hadrian emperor		
161	Marcus Aurelius emperor		
193-197	Civil War	195	Debasement of silver
232	Persian War		
249-251	Trajan Decius		Withdrawal of denarii
253-268	Goths appear	Collapse of silver, end of bronze, debasement of gold	
284	Diocletian emperor		Reforms of gold, silver and bronze
324	Constantine, first Christian emperor		
337	Founding of Constantinople	355-400	Plentiful silver
364	Empire divided		
410	Goths burn Rome		
412	Vandals take Spain		
439	Vandals plunder Italy		
455	Vandals plunder Rome		
458	Franks conquer Paris		
466	Visigoths establish king under Eric		

Source on Coinage: Burnett, Andrew, Coinage in the Roman World, 1987, p. 162-163

Timeline J.16 Timeline for Mineral Acids

Date:	Event	
300 A.D.	Leyden papyrus X	Describes false Ag/Au recipe
722-815	Seventy Books	Jabir ibn Hayyan
865-925		Abu-Bakr Muhammed ibnZakariya al Razi (Rhazes),Persia
980-1037	Persian medicine	Abu Ali al-Hussin ibn Abdallah ibn Sina (Avicenna)
1214-1292	Opus Majus	Roger Bacon
1250 A.D.	Speculum Naturale	Vincentius Bellovacensis, compendium of Pliny, Aristotal, Plato, Theophrastus, vitruvius, and Rhazes.
1300	1st description of mineral acids	Geber
1317	Alchemies prohibited	PopeJohn XXII
1323	excommunication of friars	HerveNedelic, General of the Dominican Friars
1330	Physicus: Intro. To the Artsof Alchemy	Petrus Bonus
1380	Alchemical tools forbidden	Charles V of France
1404	Alchemy forbidden	Henry IV
1418	Alchemy forbidden	Venice
1500	Assayers descriptions of acid	Anonymous
1530		Agricola
1561-1626	applies mineral acids systematically to gold	Francis Bacon
	describes reactions of acids with gold and silver	Paracelsus
1685-1761	English process for oil of vitriol	Joshua Ward
1794	Lead acid chamber process	Johen Roebuck, M.D.

Timeline J. 17 : Co developments in Analysis and Regulation

Date	Analytical Technique	Limit of Detection	Media	Goal or Regulatory Limit	Agency
1921			***Paint***	2% metallic lead in paint; no interior	ILO
1923			***Gas***	TEL introduced	Bureau of Mines
1925	Dithizone	20 ppb-5 ppm			
1933			***Work***	150 µg/m^3 (**<u>Goal</u>**)	US Public Health
1957			***Work***	500-200 µg/m^3	
mid 1960s			***Blood***	40 µg/dL acceptable	CDC
1960s	AAS	20-50 ppb			
	ASV	20-50 ppb			
1970s	GFAA	0.05-50 ppb			
	Keppler Report recommends proficiency testing				
1971			***Paint***	LBPPPA	President Nixon
	(Lead-Based Paint Poisoning Prevention Act)				
			Work	150 µg/m^3 (**<u>Goal</u>**)	ACGIH
1973			***Paint***	Residential Paint <0.5%	U.S. Congress
1974			***Water***	Safe Drinking Water Act (SDWA)	
1975	ZPP	>250 ppb (20-25 µg/dL)			
			Blood	30 µg/dL	CDC
			Work	100 µg/m^3`	OSHA
1976				TEL phase out	EPA
1978			***Work***	50 µg/m^3	OSHA
			Paint	Residential Paint<0.06%	U.S. Congress
1980s	LEAF	0.2 to 9 ppt			
	ICP-AES	20 ppt			
	ICP-MS	1-10 ppt			
1985			***Soil***	1000 µg/g	Minnesota (no National Standard)
1985			***Blood***	25 µg/dL	CDC
1988			***Water***	5µg/L	(Proposed Under SDWA)
1991			***Blood***	10 µg/dL	CDC
1991			***Cans***	Solder Banned in Canned Food	U.S. Congress
1992			***Paint***	Title X Lead Paint Disclosure Act	U.S. Congress
1997	Protection of Children from Environmental Health and Safety Risks				President Clinton
1997			***Paint***	200 µg/ft^2 interior floor 500 ug/ft^2 interior window sill 800 µg/ft^2 exterior window sill	EPA & HUD
2000			***Soil***		
2000			***Universal***	Ban of any chemical $T_{1/2}$ > 8 weeks 2000x accumulation fish/ocean	Denmark
2010	**<u>Goal</u>**: Elimination of Childhood Lead Poisoning				US Public Health