

## GLOBAL COMPARISON OF KNOWN PHOSPHATE DEPOSITS

### Research Notes

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The Lac à l'Original and associated deposits are part of the Proterozoic Lac-Saint-Jean Anorthosite (LSJA) Complex in Quebec. These deposits host  $P_2O_5$  in anorthosite and are representative of one of three main phosphate deposit types (Table 1).

Table 1. Sedimentary and igneous phosphate deposits. Anorthosite-hosted deposits are highlighted.

Deposit type	Igneous carbonatite	Igneous massif-type anorthosite	Sedimentary
Host rock	carbonatite	massif-type anorthosite	upwelling-related sedimentary rocks
Distribution	5% of global deposits	1% of global deposits	95% of global deposits
Shape of ore bodies	veins and lenses	sheets and lenses	bedded (stratiform)
Rare earth elements	high	low	variable
Deleterious trace elements	low	low	high
Organic matter	none	none	high
Phosphate mineralogy	apatite	apatite	carbonate fluorapatite
Associated minerals	calcite, dolomite, magnetite	pyroxene, plagioclase, ilmenite, magnetite	quartz, clay minerals, calcite, dolomite
$P_2O_5$ content	~5 to 15 wt%	~5 to 15 wt%	~8 to 35 wt%
Source	mantle (> 50 km depth)	mantle/crust (~ 30 to 50 km depth)	upwelling-related organic matter
Mineralization processes	high temperature crystallization in magma	high temperature crystallization and gravitational settling in magma	phosphate precipitation in accumulating sediment

Source: Dr. Sandeep Banerjee, Postdoctoral Fellow/ Researcher Queen's University

Most of the estimated world phosphate reserves are from sedimentary rocks (~95%) that generally contain high trace element concentrations and therefore, are less desirable for LFP battery production (Pufahl and Groat, 2017). China, Morocco, and the USA are the top producers of sedimentary hosted phosphate (USGS, 2022). Only a small portion of phosphate (~5%) is derived from igneous rocks (Pufahl and Groat, 2017), most of which is hosted in carbonatites that are mined in Russia and South Africa (El Bamiki et al., 2021).

The tables below represent the results of a comprehensive literature search that was conducted by members of the Pufahl Research Group at Queen's University, Kingston, ON. This search collected chemical data for phosphate-rich deposits from around the world. 73 deposits were identified, including deposits of sedimentary, carbonatite, and anorthosite origins. Available data was collated to include major oxides, minor elemental and REE analyses.

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Table 2. Concentrations of oxides in global phosphate deposits.

Major Oxides						
Deposit Type						
	Sedimentary	Carbonatite	Anorthosite	First Phosphate Quebec Anorthosites		
	average wt. %	average wt. %	average wt. %	Lac à l'Original average wt. %	Mirepoix average wt. %	Lamarche average wt. %
P <sub>2</sub> O <sub>5</sub> *	29.55	5.37	6.89	6.11	5.58	11.61
Al <sub>2</sub> O <sub>3</sub>	1.20	3.87	10.07	12.70	9.86	3.82
CaO	45.19	31.8	8.82	11.89	10.54	13.61
FeO	0.18	1.11	-	-	-	-
Fe <sub>2</sub> O <sub>3</sub>	1.06	3.70	29.07	22.40	27.02	37.80
K <sub>2</sub> O	0.33	0.70	0.46	0.59	0.42	0.03
MnO	0.07	0.16	0.22	0.16	0.18	0.33
Na <sub>2</sub> O	0.65	0.68	1.73	2.34	1.75	0.45
SiO <sub>2</sub>	11.15	5.83	27.41	34.50	30.61	16.73
TiO <sub>2</sub>	0.14	0.29	7.97	3.73	6.38	6.78

Table 3. Concentrations of minor elements in global phosphate deposits.

Minor Elements						
Deposit Type						
	Sedimentary	Carbonatite	Anorthosite	First Phosphate Quebec Anorthosites		
	average ppm	average ppm	average ppm	Lac à l'Original average ppm	Mirepoix average ppm	Lamarche average ppm
Al	1740.20	4.50	5.15	-	-	-
Ba	210.64	10994.19	428.90	578.13	416.40	-
Co	11.34	17.03	74.42	66.13	70.00	60.39
Cd	20.99	2.00	2.77	<0.5	0.02	8.30
Cr	159.95	32.49	294.27	55.56	86.70	-
La	125.91	566.64	31.55	40.99	40.00	40.24
Ni	51.47	40.70	104.79	21.25	152.30	0
Pb	90.72	15.97	2.13	<5	<2	0
Rb	16.12	47.62	22.92	4.13	-	54.81
Sr	1273.32	5628.22	624.13	1008.50	787.00	-
Th	9.00	43.88	0.69	0.36	-	2.04
Ti	1194.49	5900.00	-	-	-	-
U	73.56	38.11	0.29	0.13	-	0.68
V	124.33	44.95	539.10	340.25	252.40	-
Zr	88.18	323.05	32.10	79.25	<1	29.77
Cl	378.08	129.40	-	-	-	-
F	649.38	2.03	-	-	-	-

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Table 4. Concentrations of rare earth elements (REEs) in global phosphate deposits.

Rare Earth Elements						
Deposit Type						
	Sedimentary average ppm	Carbonatite average ppm	Anorthosite average ppm	First Phosphate Quebec Anorthosites		
				Lac à l'Original average ppm	Mirepoix average ppm	Lamarche average ppm
Ce	46.13	1037.63	76.49	104.95	-	109.54
Dy	1.68	24.55	8.23	8.53	-	14.00
Er	1.68	11.15	3.53	3.18	-	5.93
Eu	0.33	11.32	3.60	4.99	-	5.34
Gd	1.73	37.87	12.47	15.43	-	20.42
Ho	0.42	4.45	1.19	1.40	-	0.95
La	125.91	566.64	31.55	40.99	40.00	40.24
Lu	304.00	1.22	0.33	0.25	-	0.48
Nd	50.92	371.17	61.34	85.10	-	92.65
Pr	1.67	94.04	12.10	16.89	-	18.61
Sc	21.25	9.93	12.75	13.13	<5	4.64
Sm	7.40	51.52	13.76	17.86	-	21.65
Tb	1.10	6.30	1.74	1.80	-	2.65
Tm	-	2.37	1.15	0.34	-	0.48
Y	288.00	71.98	36.71	37.94	36.40	56.49
Yb	9.34	8.57	2.28	1.78	-	3.66

## Notes for Tables 3 and 4

' - ' no data was found

Values displayed as red. All values displayed in red text have been altered. The original values were recorded as below detection limit, or as greater than (>) or less than (<) a value. In order to include these values in average calculations, values displayed as <5 or smaller were re-recorded as "0". Values displayed as < a larger number were recorded as ½ the number (ex: <20 = 10). Values recorded as > a number were recorded as the value (ex: >1000 = 1000). Due to the bias added to the data, all altered values are written in orange. The resultant values and averages are therefore conservative.

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