minerals

Supplementary Materials: Geochemical Characterization of Rock Samples from Selected Fiji Mine Sites to Evaluate on-Site Environmental Vulnerabilities

Summary

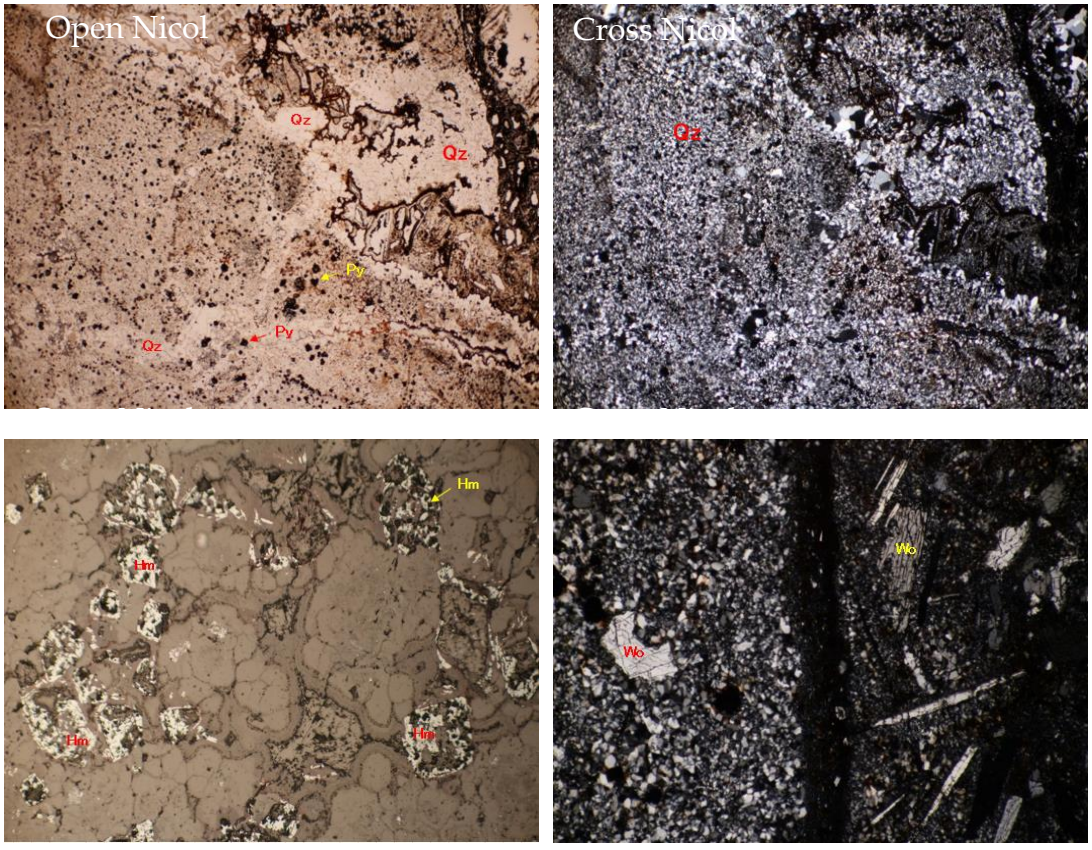
This supplementary information provides additional information on rock types, quality assurance, and quality control (QA/QC) protocols, microscopic observation, X-ray powder diffraction (XRD) percentages abundance for each mineral, leachate characteristics, saturation indices, and the principal component analysis (PCA) graph.

Table S1. Rock sample details.

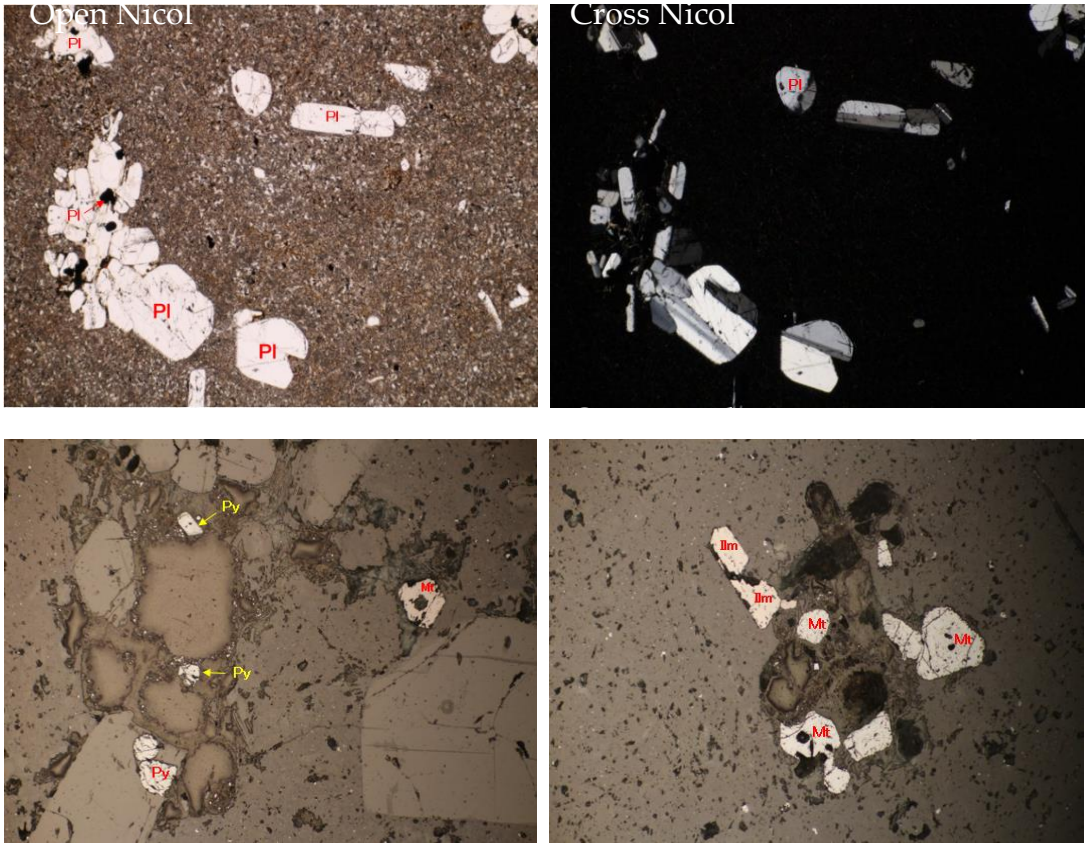
Mine Site	Rock Samples and Rock Type	Deposit Type	Site Condition
Mt Kasi	Three samples; M1—volcanic breccia, M2—silicified ore, M3—andesitic rock	High-sulfidation epithermal vein	Abandoned but under further exploration
Nukudamu	Four samples; N1, N2—oxidized andesitic rock, N3—oxidized obsidian rock, N4—pyritic pumice	Kuroko	Completely abandoned
Tuvatu	Four samples; T1—andesite, T2—biotite, T3—micro monazite, T4—mod blended monzonite	Low-sulfidation epithermal gold vein	Active mining lease, development stage
Vatukoula	Four samples; V1—aphantic basalt, V2—porphyritic andesite, V3—basalt, V4 medium coarse rained monzonite	Low-sulfidation, epithermal gold veins, porphyry Cu-style mineralization	Active mining lease, full operation
Wainivesi	One composite sample; W1—silicified andesites, pyritic andesite and dacitic ore	Volcanic massive sulfidation vein	Active and under exploration license

Table S2. Quality assurance (QA) and quality control (QC).

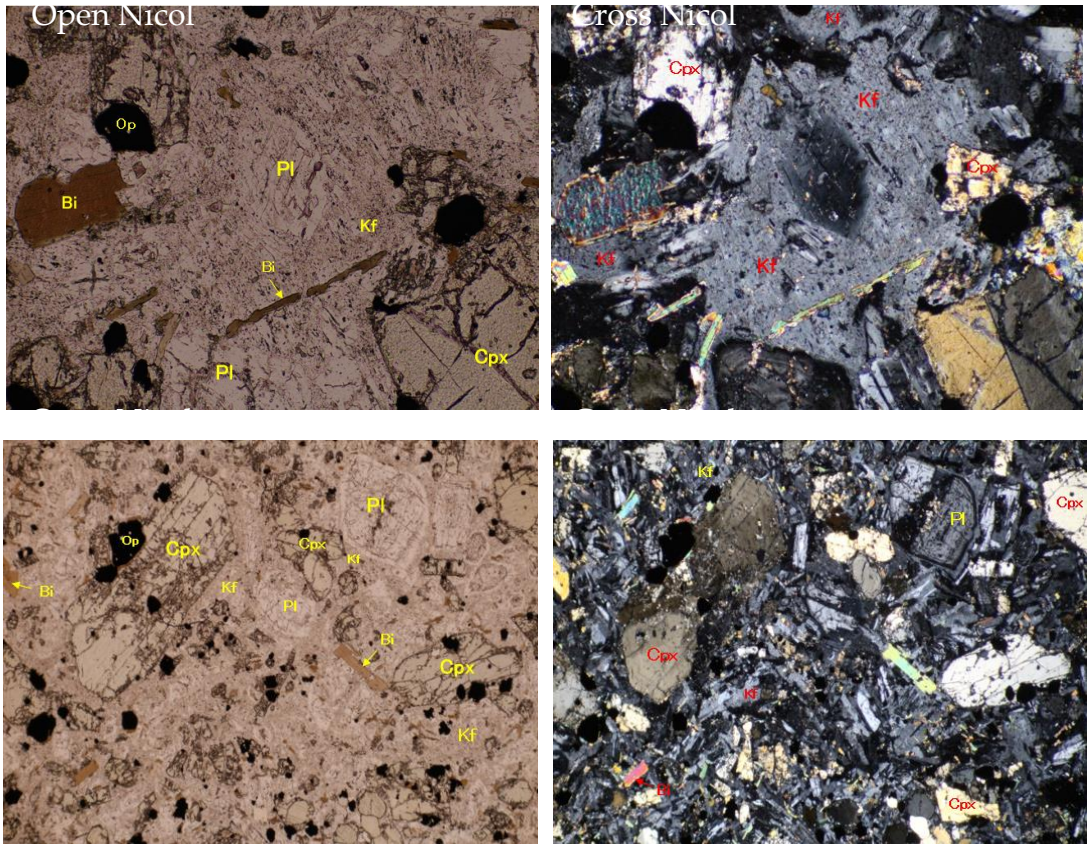
Calibration Standard for ICP-AES										
Elements	Mass concentration (w/v) ± expanded measurement uncertainty									
	Certified value (mg/L)	Uncertainty	Measured value							Traceable to SRM
			Multi Standard				SO_4^{2-} Standard			
			Std 1	Std 5	Std 10	Std 20	Std 1	Std 5	Std 10	
Ca	1009	±10	1002	996	992	1005				SRM 3109a
Cu	998	±10	970	1002	1002	997				SRM 3114a
Fe	998	±10	996	992	989	1002				SRM 3126a
Mg	999	±10	985	982	995	993				SRM 3131a
Na	1001	±10								SRM 3152a
K	1002	±10	1010	1004	1000	1005				SRM 3141a
Pb	999	±10	987	980	979	990				SRM 3128
Zn	997	±10	978	982	986	1015				SRM 3168a
SO_4^{2-}	1000						1020	996	1005	
	0.8% (coverage factor k=2 level of confidence approximately 95% (sulfate ion standard solution SO_4^{2-} 1,000) (ISO/IEC 17025:2017 and ISO 17034:2018)									



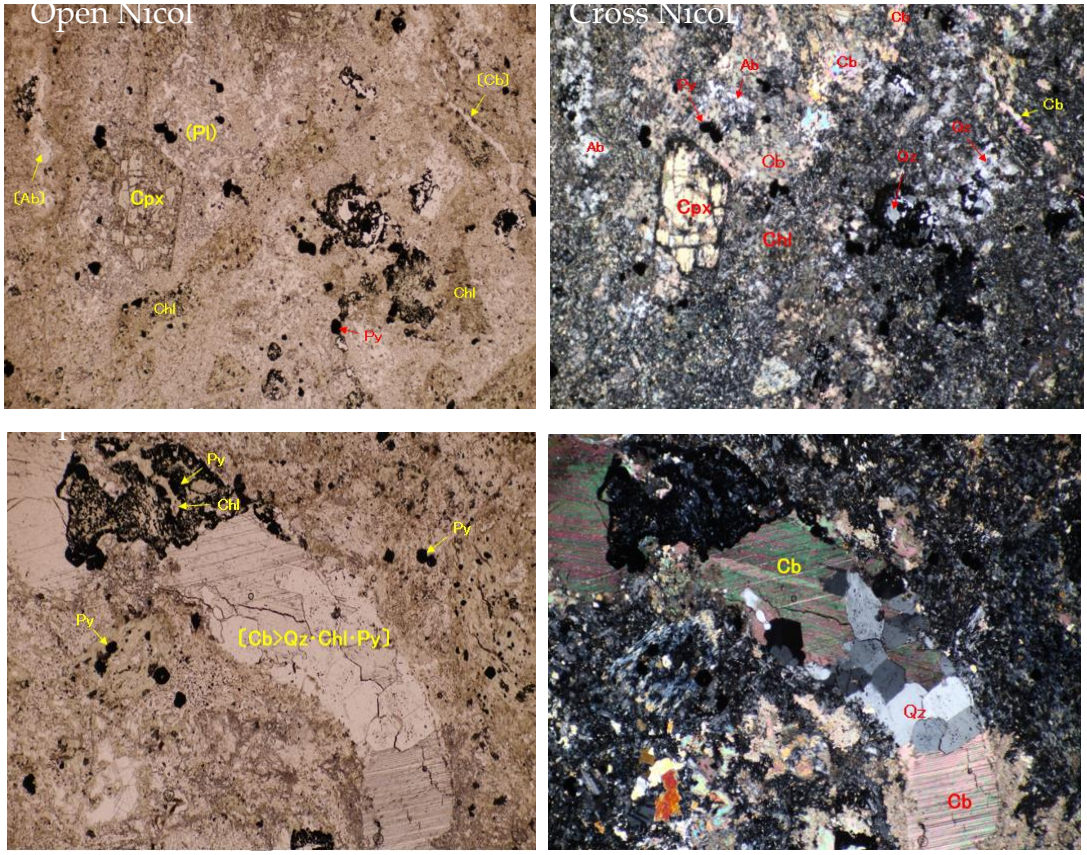
(**a**) M2—Qz: quartz, Py: pyritic minerals, Hm: hematite, and Wo: wollastonite.



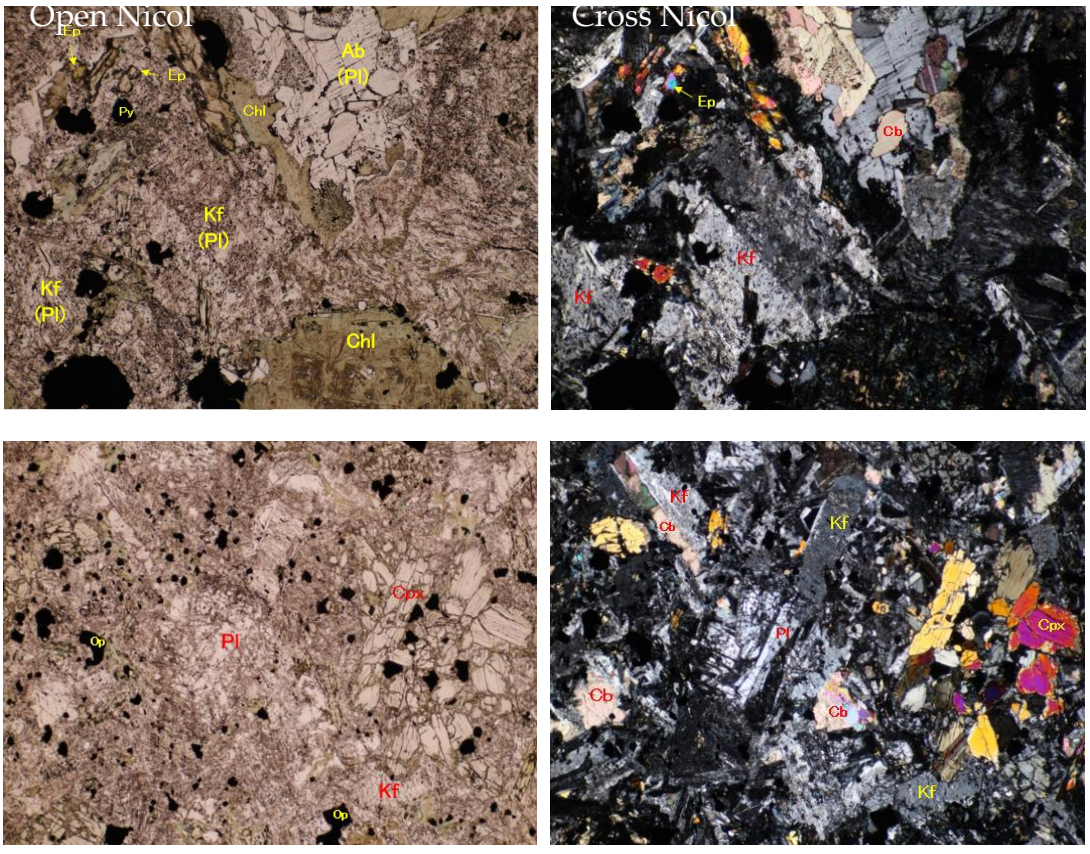
(**b**) N1—Pl: plagioclase, Py: pyritic minerals, Mt: magnetite, and Ilm: ilmenite.



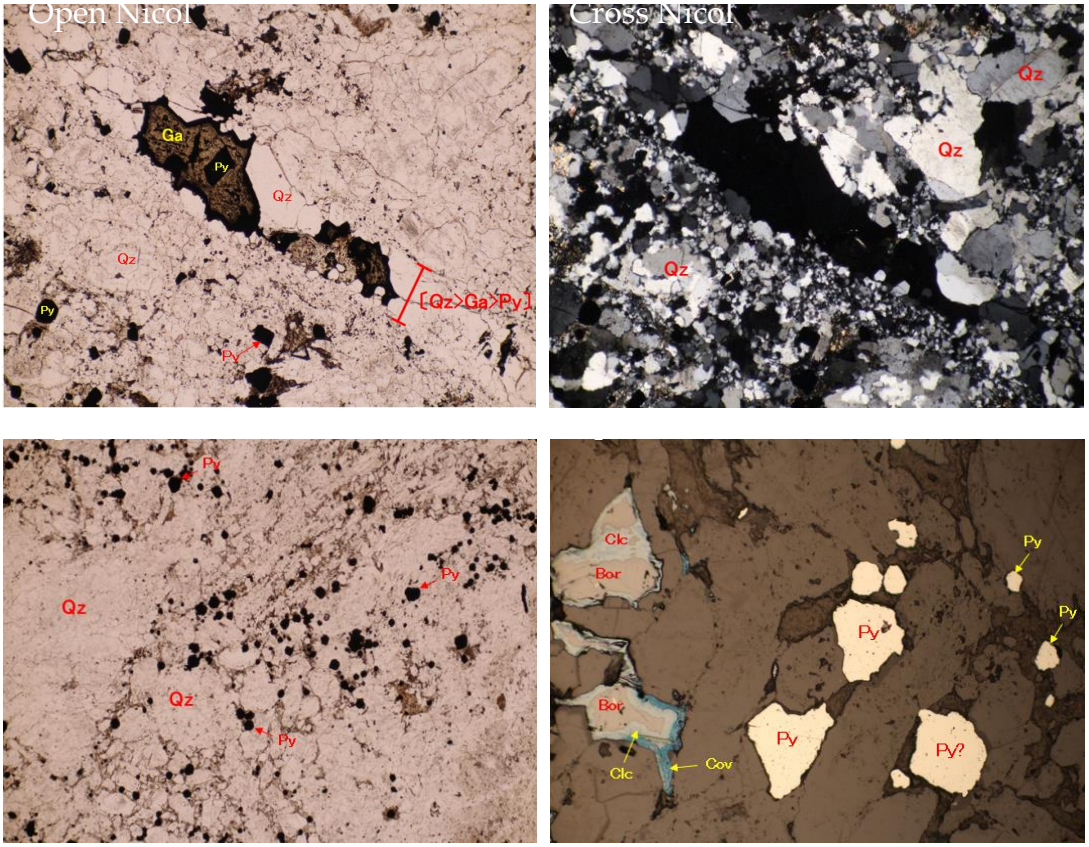
(**c**) T3—Bi: bismuth, Pl: plagioclase, Op: opaque minerals, Kf: potassium fledspar, Cpx: clinoaugite, Mt: magnetite, Py: pyritic minerals, and Bi: biotite.



(**d**) V1—Ab: albite, Pl: plagioclase, Cpx: clinoaugite, Opx: orthopyroxene, Py: pyritic minerals, Cb: carbonate minerals, Chl: chlorite, Qz: quartz, and Mt: magnetite.



(**e**) V4—Ep: epitode, Py: pyritic minerals, Kf: potassium fledspar, Ab: albite, Pl: plagioclase, Chl: chlorite, Cb: carbonate minerals, Op: opaque minerals, and Cpx: clinopyroxene.



(**f**) W1—Ga: gallium, Qz: quartz, and Py: pyritic minerals.

Figure S1. Microscopic observation of rock samples M2, N1, T3, V1, V4, and W1, under open and cross Nicol.

Table S3. XRD diffraction percentage mineralogical abundances (%) of the rock samples.

Sample / Mineral	M1	M2	M3	N1	N2	N3	N4	T1	T2	T3	T4	V1	V2	V3	V4	W1
Quartz	77.5	85.9	87.6	13.8	6.4	58.8	-	23.7	14.6	-	12.3	23.2	9.8	23.7	17.2	30.8
Nacrite	17.5	11.9	8.9	-	-	-	2.4	-	-	-	-	14.8	-	19.2	-	-
Augite	-	-	-	-	-	-	-	16.0	46.9	21.3	2.2	35.9	20.5	-	-	-
Pyrite	5.0	-	3.5	-	4.3	-	94.6	-	-	-	-	-	-	-	-	7.7
Anorthite	-	-	-	-	-	-	-	64.6	32.0	48.8	54.8	-	-	-	37.3	-
Orthoclase	-	-	-	-	-	-	-	-	-	25.2	30.93	-	44.1	-	41.2	-
Calcite	-	-	-	-	-	-	-	8.8	-	-	-	26.1	22.7	17.3	-	-
Goethite	-	-	-	-	8.9	34.3	-	-	-	-	-	-	-	-	-	-
Albite	-	-	-	47.5	-	-	3.0	-	-	-	-	-	-	-	-	-
Cristobalite	-	-	-	38.7	-	-	-	-	-	-	-	-	-	-	-	-
Chalcopyrite	-	-	-	-	2.0	-	-	-	-	-	-	-	-	-	-	6.3
Hematite	-	-	-	-	72.4	4.6	-	-	-	-	-	-	-	-	-	-
Dolomite	-	-	-	-	-	-	-	-	-	3.4	-	-	-	-	4.3	-

Diopside	-	-	-	-	-	-	-	-	7.4	-	-	-	-	39.8	-	-
Arsenopyrite		2.2	-	-	8.1											
Sphalerite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	55.2
Enargite	-	-	-	-	-	2.5	-	-	-	-	-	-	-	-	-	-

Table S4. The EC, Eh, ORP, pe, and mean concentrations of co-existing elements: Al, Na, and Si of the rock samples.

Sample	EC (mS/cm)	Eh (mV)	ORP (mV)	pe (mV)	Al (mg/L)	Na (mg/L)	Si (mg/L)
M1	0.249 ± 0.02	562 ± 18.3	362 ± 16.7	6.22	8.18 ± 0.95	1.06 ± 0.29	1.53 ± 0.15
M2	0.042 ± 0.03	538 ± 47.4	338 ± 11.8	5.81	0.03 ± 0.05	1.16 ± 1.06	0.21 ± 0.03
M3	0.13 ± 0.01	547 ± 31.1	347 ± 21.4	5.94	5.08 ± 0.42	0.64 ± 0.15	1.04 ± 0.14
N1	0.09 ± 0.005	511 ± 81.1	311 ± 26.5	5.34	0.07 ± 0.07	3.65 ± 0.18	2.78 ± 0.28
N2	0.55 ± 0.04	649 ± 23.9	449 ± 16.2	7.71	20.5 ± 2.21	1.13 ± 0.13	1.05 ± 0.19
N3	0.22 ± .005	627 ± 35.9	427 ± 23.5	7.35	0.90 ± 0.11	0.69 ± 0.12	0.77 ± 0.11
N4	1.50 ± 0.04	589 ± 15.5	389 ± 13.4	6.69	2.92 ± 0.56	0.43 ± 0.05	0.04 ± 0.05
T1	0.09 ± 0.002	453 ± 41.4	253 ± 19.3	4.34	0.36 ± 0.12	3.07 ± 0.36	0.93 ± 0.15
T2	0.13 ± 0.01	404 ± 88.4	204 ± 21.4	3.51	0.06 ± 0.10	3.44 ± 0.25	1.04 ± 0.08
T3	0.08 ± 0.002	384 ± 54.5	184 ± 29.3	3.16	0.24 ± 0.17	1.17 ± 0.08	1.80 ± 0.22
T4	0.16 ± 0.01	388 ±39.7	188 ± 37.7	3.23	0.25 ± 0.18	3.23 ± 0.38	1.07 ± 0.16
V1	0.69 ± 0.04	390 ± 63.2	190 ± 26.0	3.26	0.04 ± 0.08	2.06 ± 0.44	1.20 ± 0.28
V2	0.12 ± 0.02	415 ± 82.6	215 ± 38.7	3.69	0.30 ± 0.13	2.15 ± 0.21	1.13 ± 0.22
V3	0.31 ± 0.03	384 ± 65.5	184 ± 27.8	3.17	0.05 ± 0.08	1.29 ± 0.04	1.31 ± 0.17
V4	0.19 ± 0.01	382 ± 60.3	182 ± 27.4	3.14	0.27 ± 0.14	1.31 ± 0.03	0.69 ± 0.11
W1	0.06 ± 0.01	428 ± 91.3	228 ± 18.5	3.93	ND	0.41 ± 0.05	0.14 ± 0.06

* ND—not detected.

Table S5. Saturation indices (*Sis*) of selected mineral phases in the leachates of the rock samples.

Minerals	M1	M2	M3	N1	N2	N3	N4	T1	T2	T3	T4	V1	V2	V3	V4	W1
Alunite	−0.603	−2.271	**0.743**	**1.582**	−0.806	−5.31	−8.788	−7.173	−1.895	−6.988	−5.340	−3.660	−3.290	−8.387	−5.079	-
Diaspore	−0.689	0.369	**0.670**	**1.966**	−0.821	−2.078	−4.509	**3.127**	**3.173**	**2.951**	**2.926**	**2.448**	**3.402**	**1.887**	**2.984**	-
Chalcedony	−0.659	−1.521	−0.821	−0.930	−0.824	−0.949	−2.234	−0.879	−0.822	−0.592	−0.823	−0.762	−1.326	−0.747	−1.011	−1.692
Cristobalite	−0.859	−1.72	−0.921	−0.598	−1.023	−1.148	−2.433	−1.078	−1.021	−0.791	−1.022	−0.961	−1.525	−0.946	−1.210	−1.891
Ferrihydride	−10.38	−9.07	−9.824	−8.530	−10.847	−10.925	−13.163	−5.70	−5.632	−5.430	−5.415	−5.692	−5.706	−5.706	−5.436	−7.460
Gibbsite	−1.150	−0.391	−0.202	**1.105**	−1.71	−2.946	−5.314	**2.609**	**1.797**	**2.068**	**2.043**	**1.574**	**2.529**	**1.014**	**2.117**	-
Goethite	−7.558	−6.249	−7.015	−5.702	−8.032	−8.091	−10.331	−2.872	−2.876	−2.596	−2.589	−2.856	−2.875	−2.875	−2.605	−4.630
Gypsum	−3.227	−4.181	−3.451	−2.890	−1.621	−2.992	−2.522	−3.617	−2.413	−3.358	−2.555	−0.923	−2.720	−1.686	−2.10	−3.009
Quartz	−0.202	−1.064	−0.301	0.058	−0.901	−2.260	−1.776	−0.420	−0.363	−0.133	−0.365	−0.303	−0.868	−0.289	−1.086	−1.234
Kaolinite	−3.434	−3.040	−3.120	2.397	−4.029	−6.785	−14.217	**3.766**	**3.971**	**3.988**	**3.47**	**2.642**	**3.419**	**1.548**	**3.215**	-
Hydrozincite	-	-	-	−22.366	-	-	-	-	-	-	-	-	-	-	-	−10.98
Smithsonite	-	-	-	−3.960	-	-	-	-	-	-	-	-	-	-	-	−2.989
Calcite	-	-	-	−5.627	-	-	-	−3.040	−2.978	−2.905	−2.562	−1.762	−3.268	−1.679	−2.954	−5.61
Dolomite	-	-	-	−11.49	-	-	-	−7.398	−7.268	−6.438	−6.298	−4.948	−1.525	−4.133	−7.111	−12.55
Anglesite	-	-	-	-	-	−3.099	−1.910	-	-	-	-	-	-	-	-	−2.995
Hydrocerrusite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	−10.42

Cerrusite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	−3.987

* SI > 0 saturated (in bold), SI < 0 unsaturated, and ± 0.5 apparent equilibrium.

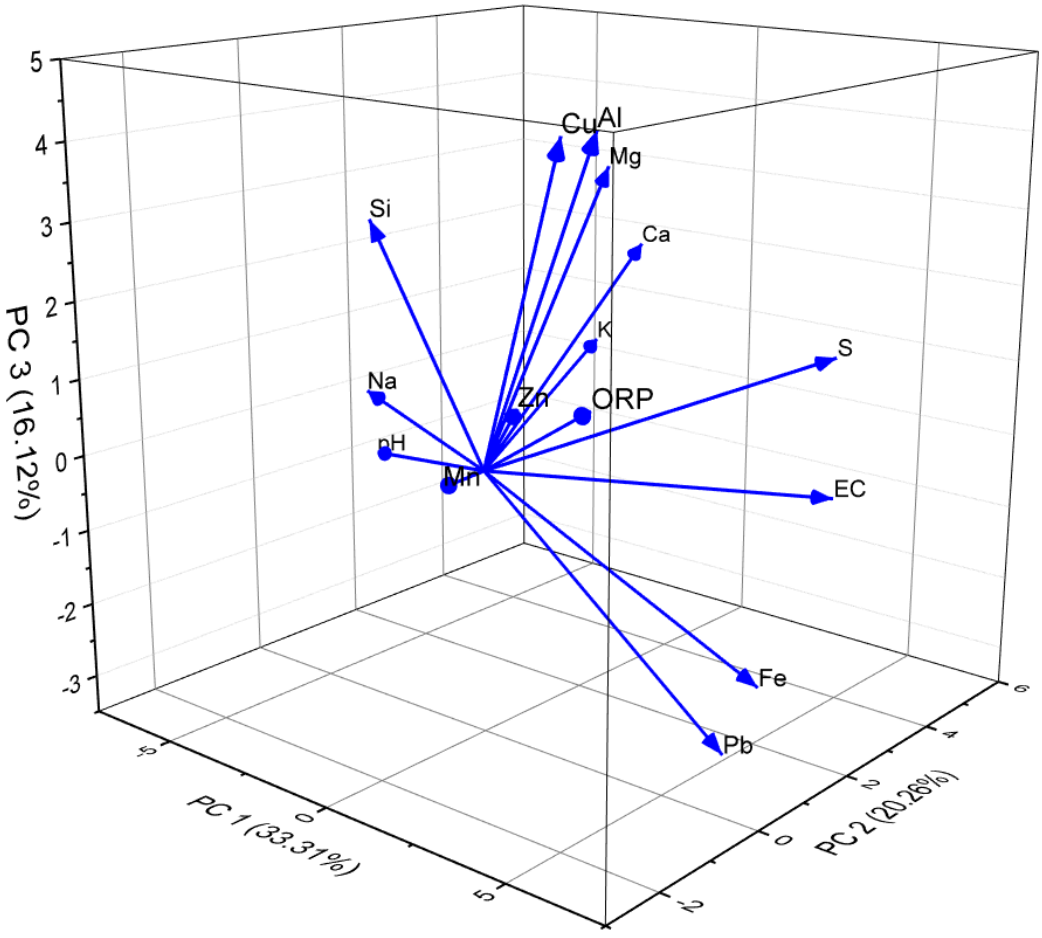


Figure S2. Graphical presentation of the PCA results showing the first 3 components with significant inter-correlated dependent variables.