

## Supplementary materials

# Lanthanum-Modified Phosphogypsum Red Mud Composite for the Co-Adsorption of Cadmium and Arsenic: Mechanism Study and Soil Remediation

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### Text S1

#### Determination of the basic physico-chemical properties and heavy metal concentration in tested Soil

**pH measurement:** During pH measurement, 10.00 g of the soil sample was placed into a 100 mL centrifuge tube. Then, 25 mL of CO<sub>2</sub> free water was added, and the mixture was shaken at a speed of 250 r·min<sup>-1</sup> at 25°C for 2 hours. After allowing it to stand for 30 minutes, the pH was measured using a pH meter (S210, Mettler-Toledo Instruments Shanghai Co., Ltd. China).

**CEC determination:** Under conditions of 20 °C, cobalt hexamine chloride (c [Co(NH<sub>3</sub>)<sub>6</sub>Cl<sub>3</sub>] = 1.66 cmol/L, superior purity) was used as the extracting solution to extract soil. Cations in the soil was exchanged into the solution by cobalt hexamine chloride. Cobalt hexamine chloride exhibits characteristic absorption at 475 nm in UV-visible spectrophotometry

(UV-1800PC, Shanghai Meixi Instruments Co., Ltd. China). The absorbance was directly proportional to the concentration. The soil cation exchange capacity was calculated based on the difference in absorbance of the extracting solution before and after extraction using the following formula:

$$CEC = \frac{3(A_0 - A)V}{bmw_{dm}}$$

In the formula: CEC represents the cation exchange capacity in cmol(+) per kilogram;  $A_0$  is the absorbance of the blank sample; A is the absorbance of the sample or the corrected absorbance; V is the volume of the extracting solution in milliliters (mL); 3 is the charge number of  $[Co(NH_3)_6]^{3+}$ ; b is the slope of the standard curve; m is the sample quantity in grams (g);  $W_{dm}$  represents the dry matter content of the soil sample in percentage (%).

The determination of soil organic matter, total phosphorus, total potassium, total nitrogen, available phosphorus, available potassium, and alkaline nitrogen refers to "Methods of Soil Agricultural Chemical Analysis" (Lu Rukun, 2000).

Lu Rukun. Methods of Soil Agricultural Chemical Analysis. China Agricultural Science and Technology Press, 2000.

**Determination of total Cd in soil:** Digestion was performed using the  $HNO_3$ -HCl- $HClO_4$  method. Accurately weigh 0.5000 g and add 7 mL of  $HNO_3$  and 5 mL of HCl separately. Heat on a hot plate until the brown solution was digested (only a small amount remains). Remove from heat and cool. Add 3 mL of  $HClO_4$ , continue heating until a large amount of white smoke appears, then remove the acid by decantation. Continue until the sample turns grayish-white. Remove the sample, cool and make up to volume, filter through a 0.45  $\mu m$  membrane filter, and measure using inductively coupled plasma mass spectrometry (ICP-MS) (ICAP RQ, Thermo Fisher Scientific, USA). National soil standard substance (GBW-70404a) is used for quality control analysis.

**Determination of total As in soil:** Accurately weigh 0.2000 g, add 10 ml of 1+1 aqua regia, boil in a water bath for 2 hours with repeated shaking. After completion of boiling, cool and make up to volume, filter through a 0.45  $\mu m$  membrane filter, and measure using an atomic fluorescence spectrometer (AFS-9120, Beijing Jitian Instrument Co., Ltd. China). National soil

standard substance (GBW-70404a) was used for quality control analysis.

**Table S1.** Chemical composition of PG,RM,PR and L-PR(w/%).

Sample	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	CaO	MgO	Na <sub>2</sub> O	SO <sub>3</sub>	La <sub>2</sub> O <sub>3</sub>	Others
PG	0.55	0.60	2.15	42.10	0.12	0.06	52.66	-	1.76
RM	17.30	22.71	17.29	24.94	1.61	6.21	1.89	-	8.05
PR	14.23	18.67	14.54	27.45	1.39	5.12	11.71	-	6.80
L-PR	14.77	19.78	15.79	22.39	1.47	5.33	4.56	6.24	9.67

**Table S2.** Basic physical and chemical parameters of tested soil.

	pH	CEC (cmol+/kg)	OM (g/kg)	TP	TK	TN	AP (mg/kg)	AK	HN	Total Cd	Total As
Tested soil	5.02	6.06	35.32	1.38	13.61	2.38	12.91	321.78	172.60	2.17	82.65

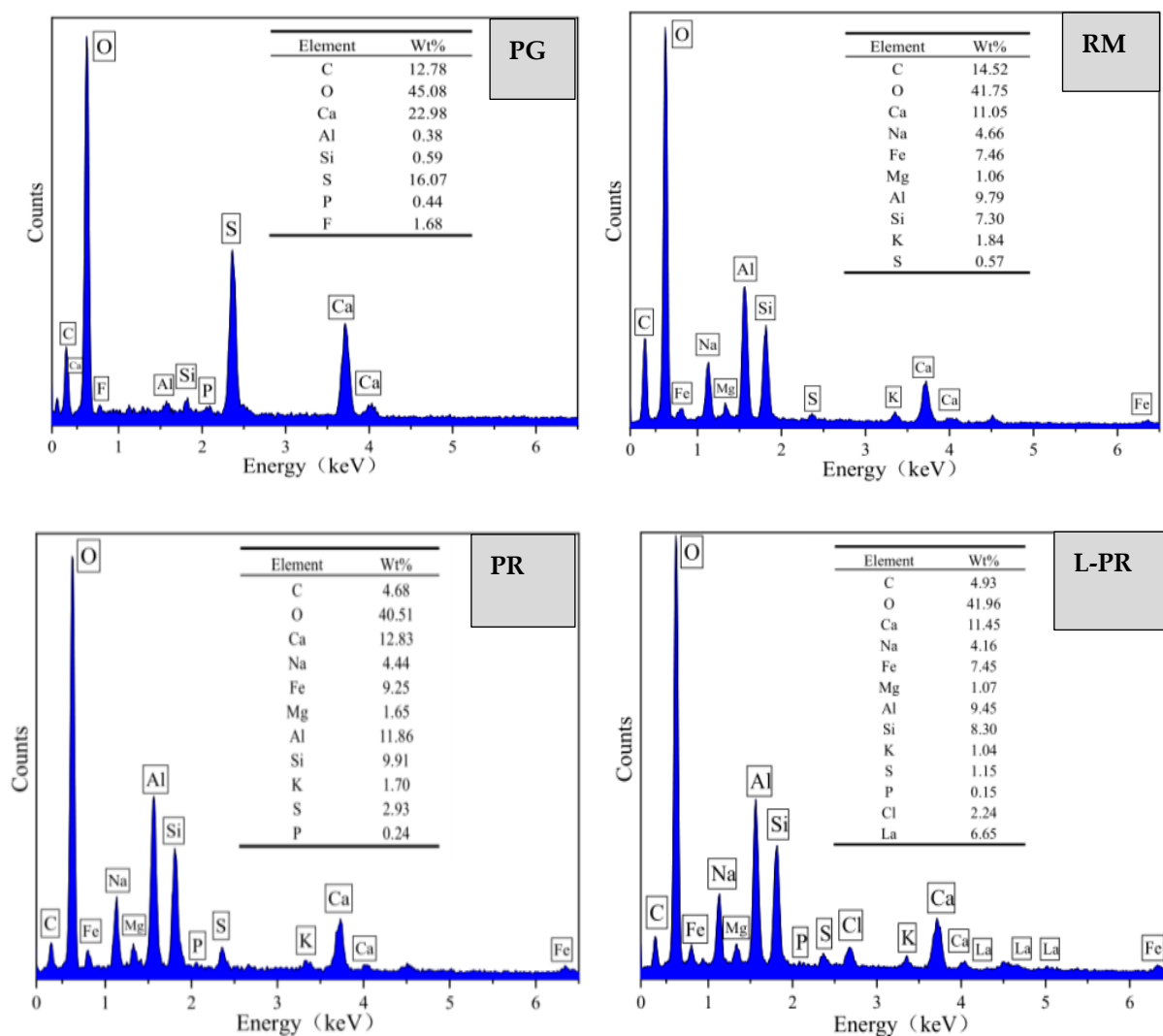
**Table S3.** Basic physical and chemical properties of PG,RM,PR and L-PR.

Sample	Zn (mg/kg)	Cu	Ni	Pb	Cd	As	S <sub>BET</sub> (m <sup>2</sup> /g)	V <sub>tot</sub> (cm <sup>3</sup> /g)	Pore width (nm)	pH
PG	3.69	13.66	2.05	3.53	0.02	-	0.592	0.003	19.796	5.05
RM	42.27	62.26	87.47	41.90	1.01	29.66	7.483	0.037	19.779	11.78
PR	42.37	18.24	25.50	8.31	0.35	12.98	8.866	0.039	17.662	8.99
L-PR	43.35	17.13	22.41	8.31	0.15	9.95	8.033	0.026	13.031	6.98

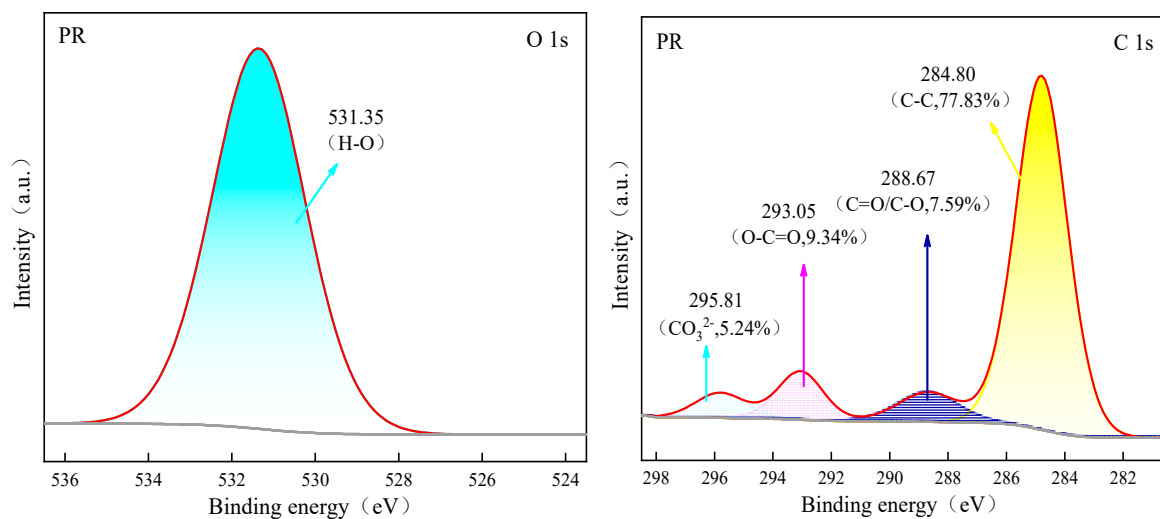
**Table S4.** Procedure for the extraction of availability and fractions of As and Cd in soil.

Methods	Steps	Fractions	Extractants	Extraction conditions
Improved BCR sequential extraction method	F1	Acid-soluble	0.1 mol/L CH <sub>3</sub> COOH	Shake for 16 h at 25°C, centrifuge
	F2	Reducible	0.5 mol/L NH <sub>2</sub> OH·HCl	Shake for 16 h at 25°C, centrifuge
	F3	Oxidizable	30%H <sub>2</sub> O <sub>2</sub> , 1 mol/L CH <sub>3</sub> COONH <sub>4</sub>	H <sub>2</sub> O <sub>2</sub> was added and allowed to stand for 1 hour , heat at 85°C in a water bath until nearly dry, Cool down, Repeat the above steps. Then CH <sub>3</sub> COONH <sub>4</sub> was added and shaken for 16 h at 25°C, centrifuge

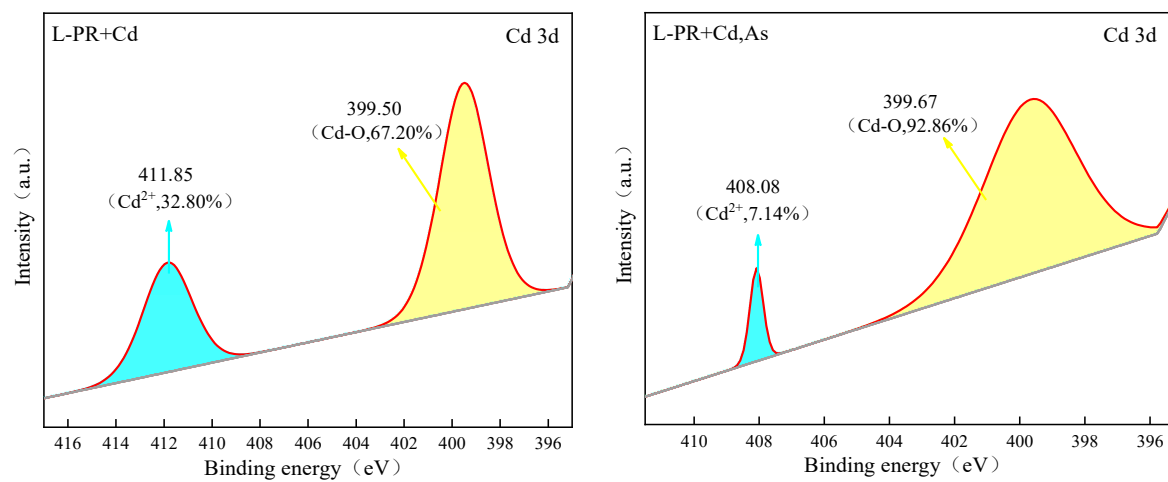
	F4	Residual	-	Digestive residue
CaCl <sub>2</sub> -Cd	-	Available Cd	0.01 mol/L CaCl <sub>2</sub>	1:10 soil-water ratio, shake for 2 h at 20°C
NH <sub>4</sub> H <sub>2</sub> PO <sub>4</sub> -As	-	Available As	0.05 mol/L NH <sub>4</sub> H <sub>2</sub> PO <sub>4</sub>	1:25 soil-water ratio, shake for 16 h at 20°C



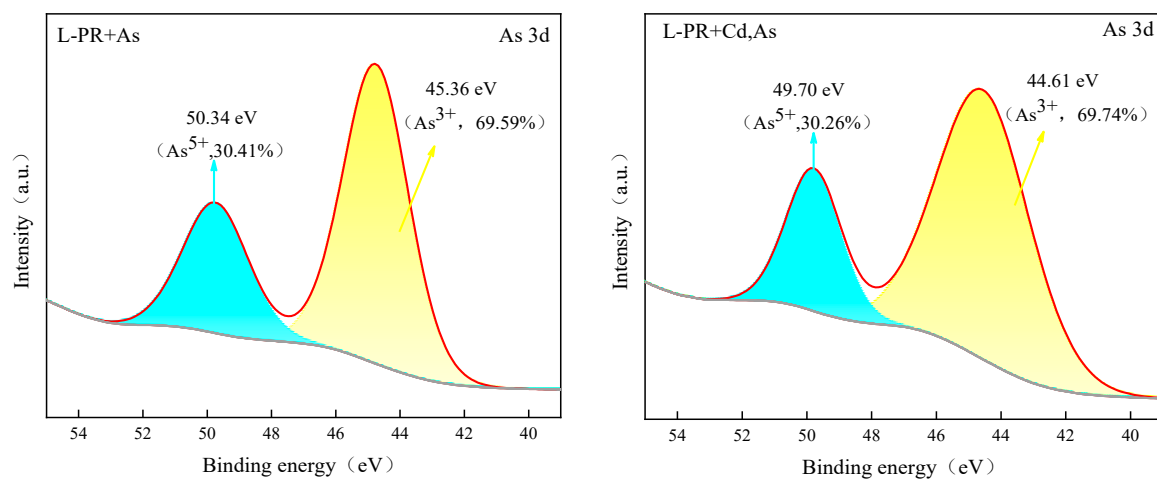
**Figure S1.** EDS images of PG, RM, PR and L-PR.



**Figure S2.** O 1s and C 1s spectra on PR surface.



**Figure S3.** Cd 3d spectra on L-PR surface.



**Figure S4.** As 3d spectra on L-PR surface.

## References

Lu Rukun. Methods of Soil Agricultural Chemical Analysis. China Agricultural Science and Technology Press, 2000.