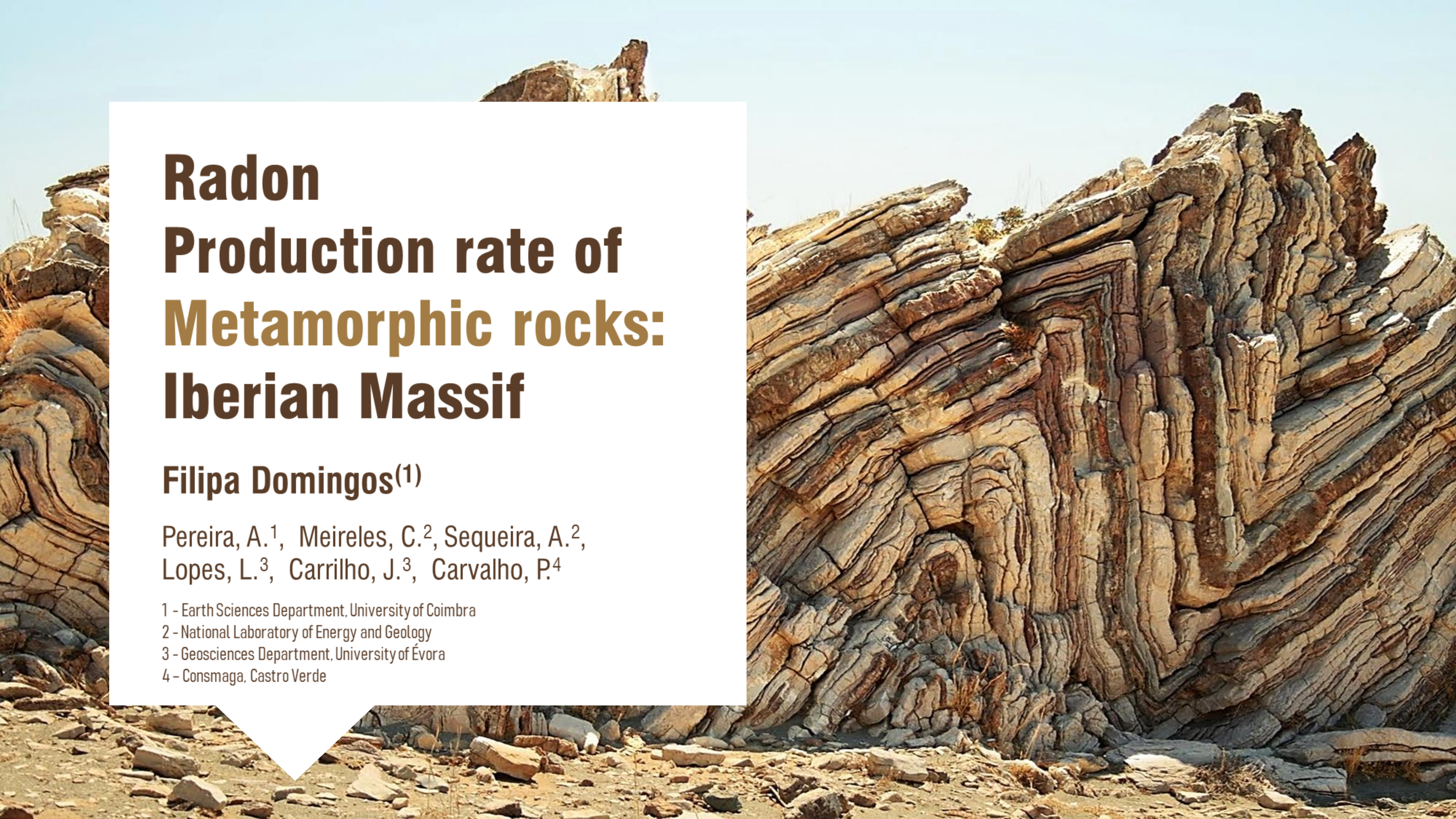

Radon Production rate of Metamorphic rocks: Iberian Massif

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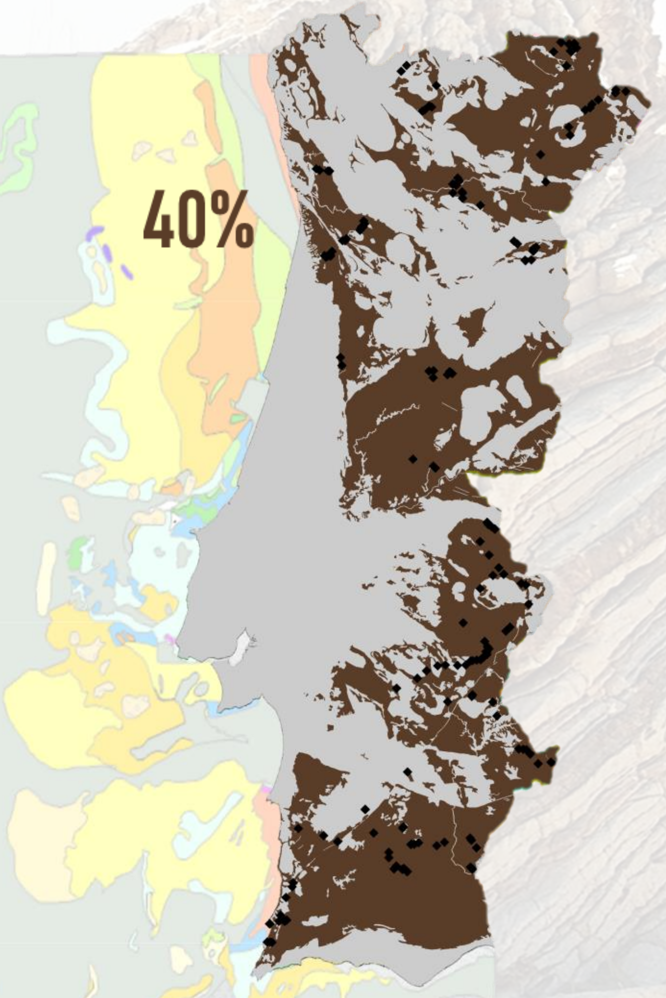
Geological setting

- **Sedimentation from Pre-Cambrian onwards;**
- **Variscan Orogeny[1]:**
  - Barrovian type regional metamorphism:
    - Greenschist facies (300 – 450ºC)
  - High pressure metamorphism:
    - Obduction of allochthonous terranes
  - Contact metamorphism
    - Intrusion of granitic rocks



Goals

(1) Characterize the radon production rate of metamorphic rocks outcropping in the Iberian Massif;

(2) Assess the influence of metamorphism in the radon production rate of the protolith;

(3) Assess the factors that influence the radon production rate of metamorphic rocks;

Contents

- Materials and Methods;
- Classification of metamorphic rocks;
- Results: Radon production rate (PRn):
  - Type of metamorphism
  - Metamorphic grade
  - Physical(/chemical) alteration
  - Etc.
- Discussion: Geogenic radon potential.

Sampling

- *Ca.* **264 samples collected:**

  Reference outcrops;

  Collection of 2-3 kg of sample;

    Determination of porosity, bulk and grain density

    Determination of Ra-226 activity by gamma-spectrometry

    Determination of Rn-222 emanation coefficient w/ the accumulation method

    Computation of the **Rn-222 production rate**:

    (i.e. the amount of radon available for transport)

Materials and Methods

- *Ca.* 264 samples processed[2,3]:

Porosity, grain and bulk density: NP EN 1936:2008

Samples were heated to 70 °C until reaching a constant weight - Dry mass (m_d);

Submitted to a negative pressure during a 2 h interval;

Immersion during 24 h and weighing - Immersed mass (m_i);

Saturated sample weighing – Saturated mass (m_s);

$$\rho = \frac{m_d}{m_d - m_i} \times \rho_w \qquad \rho_{Bulk} = \frac{m_d}{m_s - m_i} \times \rho_w \qquad \phi = \frac{\rho}{\rho_{Bulk}} - 1$$

Dried, milled (< 2 mm) and stored in *Marinelli* beakers;

Materials and Methods

- *Ca.* **264 samples processed[2,3]:**

^{226}Ra was determined with an Ortec™ NaI (3″ x 3″):

Detector efficiency of 48% and resolution of 58.08 keV at 2614.5 keV;

Calibration in the energy range of 1.2 MeV to 3 MeV;

Calibration with RGU-1, RGK-1 and RGTh-1 IAEA standards;

Ra-226 derived from Bi-214 1767.5 keV photopeak assuming secular equilibrium;

Detection limit estimated at 0.6 Bq for Bi-214.

Each measurement was performed with a 10h counting time;

Spectra were interpreted with ScintiVision-32 (version 2, Ortec);

Materials and Methods

- *Ca.* 264 samples processed[2,3]:

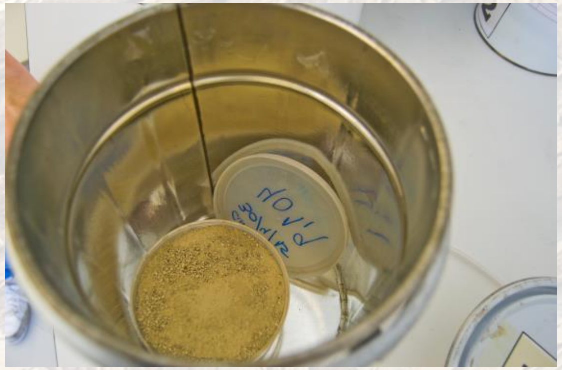
^{222}Rn exhalation measured w/ the accumulation method;

Stainless steel radon-proof containers with a 5L volume;

Exhaled Rn-222 measured with AlphaGuard (PQ2000 PRO/ODL, Saphymo)

Air pumped in continuous flow mode with a leakage proof AlphaPump

Background subtraction and correction of measured Rn-222 concentration to match equilibrium concentration



^{222}Rn emanation coefficient and ^{222}Rn Production Rate;

$$E = \frac{C_e \times V}{W \times A_{Ra}}$$

$$PRn = A_{Ra} \times E \times \rho \times \lambda$$

Classification of metamorphic rocks

n	Lithology
9	Carbonate rocks, Marbles, etc.
7	Conglomerates and Breccias
19	Quartz-feldspathic rocks
111	Pelites
8	Iron-rich metamorphic rocks
63	Organic matter-rich rocks
22	Contact metamorphism (Schists, migmatites)
20	Metagranitoids
5	High grade metamorphic rocks

Texture

Composition

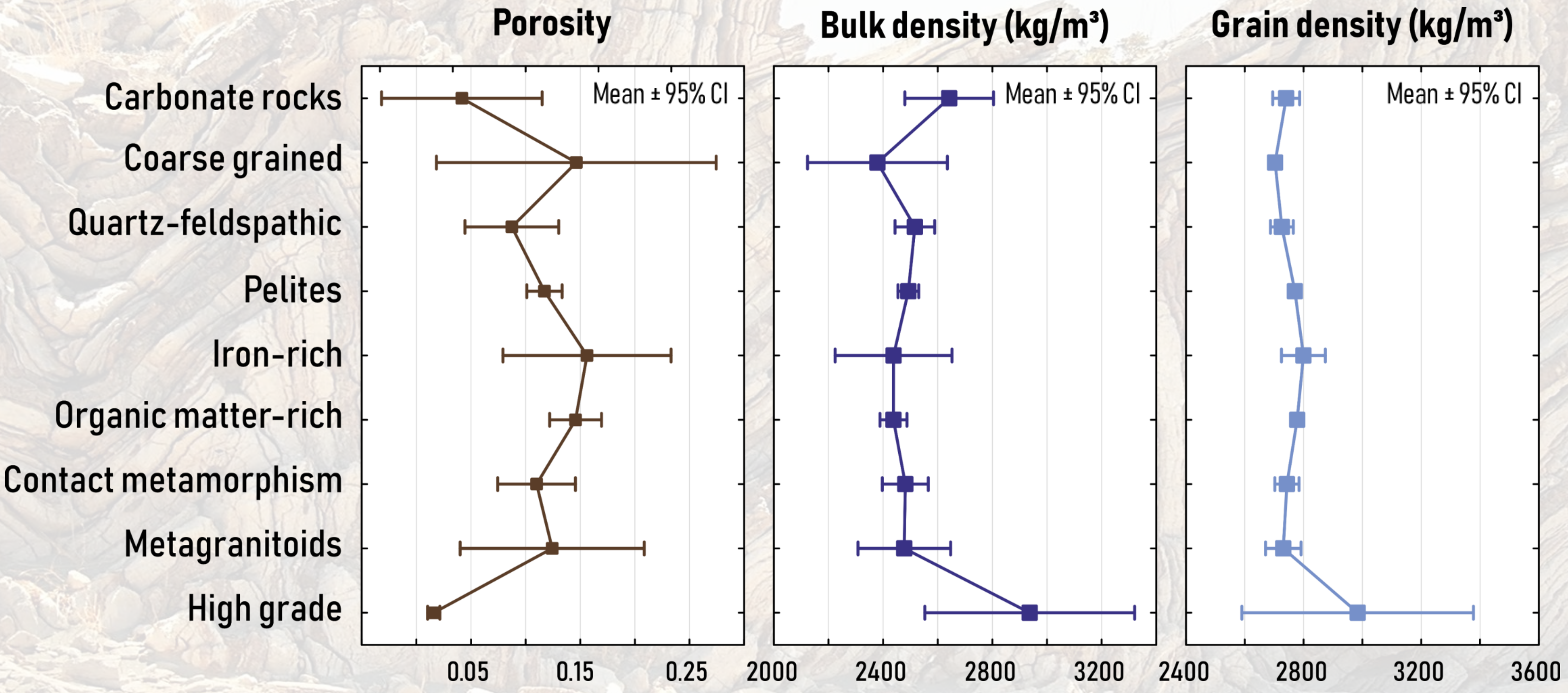
Radon Production Rate

Protolith

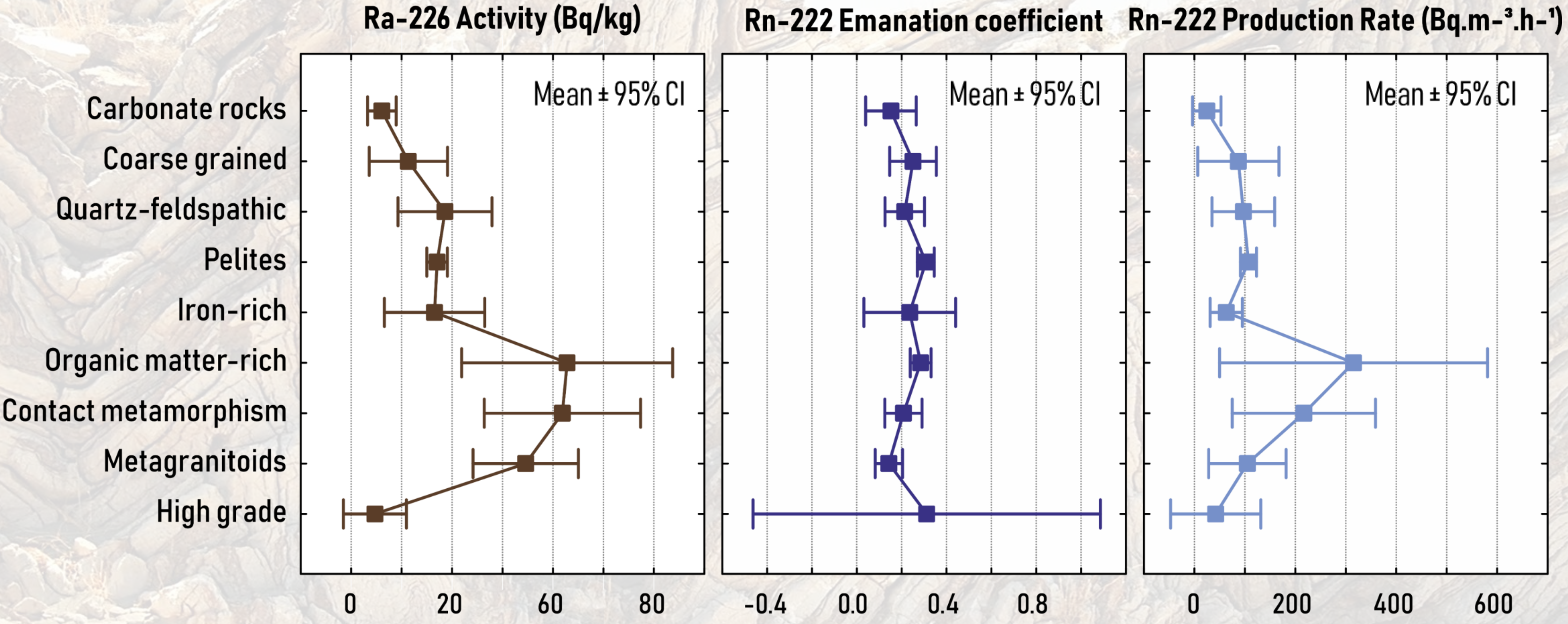
Type of metamorphism

Metamorphic grade

Physical properties of metamorphic rocks



Radiological properties of metamorphic rocks



Metasediments vs. Sedimentary rocks

Sêco et al. 2016[4], 2018[5] – Sedimentary rocks of the Lusitanian Basin

	Carbonate rocks	Quartz-feldspathic	Pelites	Organic matter rich	Limestones[4]	Sandstones[4]	Fine-grained sedimentary[4]	Organic matter rich[5]
Ra-226 (Bq/kg)	6 ± 4	19 ± 19	17 ± 11	3.47 ± 6.7 (eU in ppm)	15 ± 6	29 ± 21	56 ± 16	3.47 ± 1.5 (eU in ppm)
Rn-222 (Bq/kg)	1 ± 1	4 ± 5	5 ± 4	0.10 ± 0.30 ($Bq.kg^{-1}.h^{-1}$)	1 ± 1	4 ± 6	8 ± 5	0.05 ± 0.03 ($Bq.kg^{-1}.h^{-1}$)
Rn-222 Emanation	0.15 ± 0.12	0.21 ± 0.17	0.31 ± 0.19	0.28 ± 0.17	0.10 ± 0.07	0.10 ± 0.06	0.13 ± 0.08	0.19 ± 0.12
Rn-222 production rate ($Bq.m^{-3}.h^{-1}$)	25 ± 27	97 ± 112	107 ± 76	315 ± 905	19 ± 13	57 ± 89	100 ± 65	ND

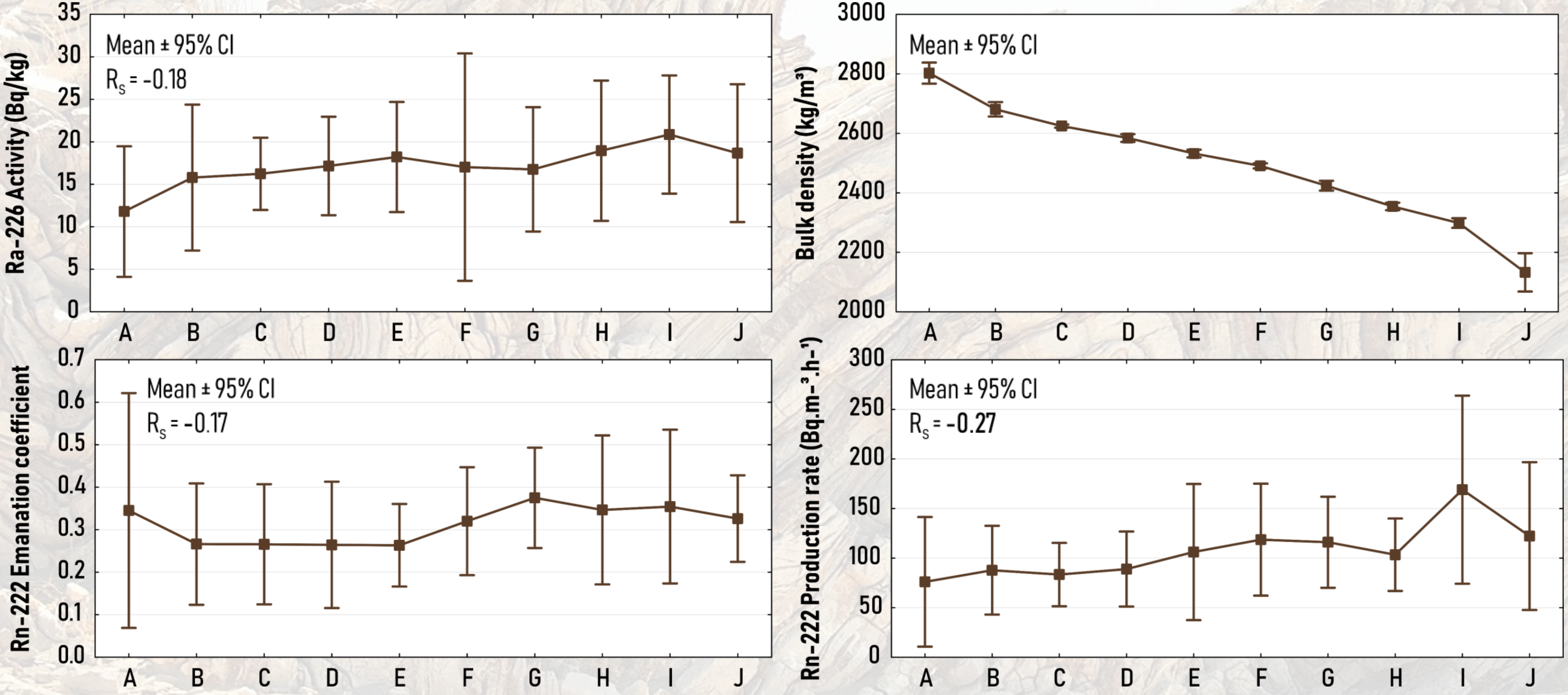
Metagranitoids vs. Granitic rocks

	Metagranitoids (present study)	Pereira et al. 2017[2] – Granitic rocks of the Iberian Massif						
		A1	A2	B1	B2	C1	C2	C3
Ra-226 (Bq/kg)	35 ± 22	61 ± 37	56 ± 20	81 ± 28	95 ± 35	82 ± 16	141 ± 96	71 ± 30
Rn-222 exhalation (Bq/kg)	5 ± 7	18 ± 14	56 ± 20	24 ± 13	32 ± 16	15 ± 8	20 ± 17	22 ± 16
Rn-222 Emanation	0.14 ± 0.12	0.30 ± 0.18	0.20 ± 0.11	0.27 ± 0.13	0.32 ± 0.10	0.19 ± 0.12	0.19 ± 0.18	0.33 ± 0.19
Porosity (%)	0.12 ± 0.17	0.03 ± 0.01	0.02 ± 0.01	0.05 ± 0.02	0.06 ± 0.03	0.02 ± 0.01	0.02 ± 0.02	0.03 ± 0.02
Grain density (kg/m^3)	2731 ± 125	2670 ± 19	2680 ± 20	2680 ± 55	2700 ± 55	2750 ± 59	2660 ± 35	2650 ± 29

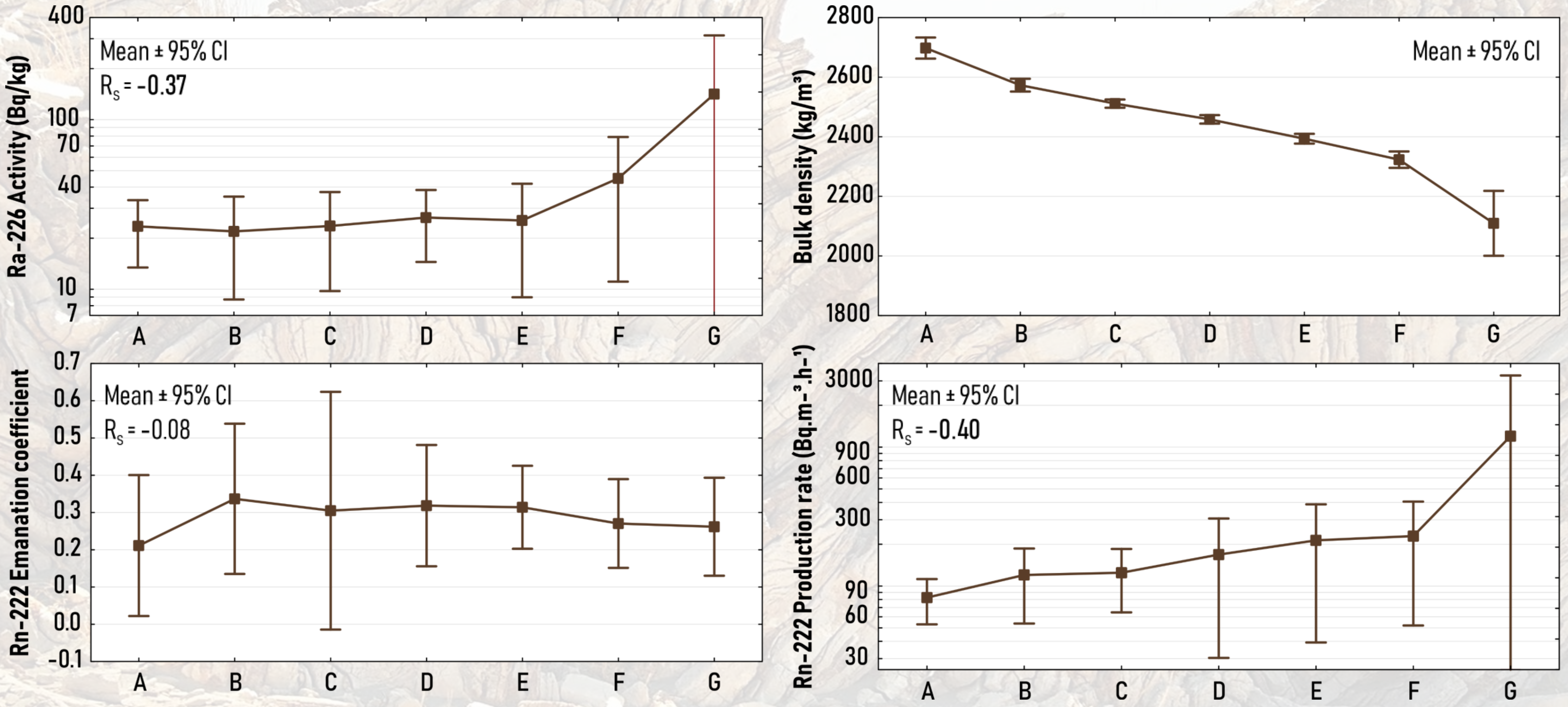
Metamorphic grade

	Ra-226 Activity	Rn-222 Emanation	Rn-222 Production rate	Porosity	Bulk density	Grain density
Ra-226 Activity	1.00					
Rn-222 Emanation	**-0.29**	1.00				
Rn-222 Production rate	**0.50**	**0.60**	1.00			
Porosity	**0.23**	**0.17**	**0.29**	1.00		
Bulk density	**-0.32**	-0.09	**-0.27**	**-0.93**	1.00	
Grain density	**-0.24**	**0.20**	0.06	0.04	**0.30**	1.00

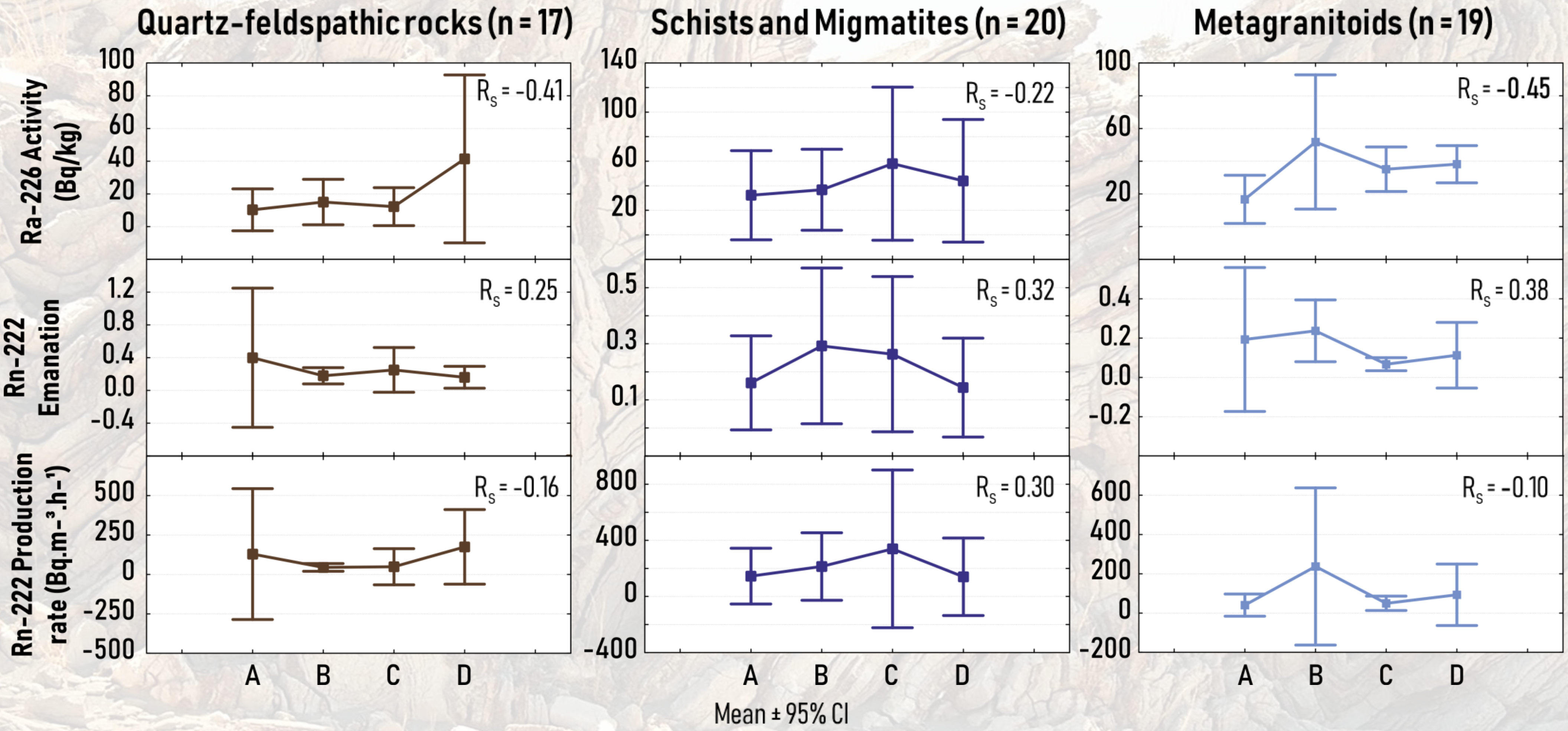
Physical alteration of Pelites (n = 111)



Physical alteration of Organic matter-rich rocks (n = 56)



Physical alteration (10≤ n ≤ 20)



Final remarks

- Contact metamorphism:
  Higher Ra-226 activity + Similar Rn-222 emanation = Higher Rn-222 production rate
- High grade metamorphism:
  Lower Ra-226 activity + Similar Rn-222 emanation = Lower Rn-222 production rate

] Regional metamorphism

- Increase of the metamorphic grade (<-> decrease of porosity and increase of density):
  Lower Ra-226 activity + higher Rn-222 emanation;
  Metamorphism of sedimentary rocks:
  Lower Ra-226 activity + Higher Rn-222 emanation = Similar Rn-222 production rate
  Higher Rn-222 emanation coefficient ⇢ Increase of the specific surface area of minerals
  Metamorphism of granitic rocks:
  Lower Ra-226 activity + Lower Rn-222 emanation = Lower Rn-222 production rate
  Lower Rn-222 emanation coefficient ⇢ Removal of labile Ra-226/U-238; **Inherited(?)**

Final remarks

- Physical alteration of metamorphic rocks:

    Significant increase of Pelites Rn-222 production rate (from 76 to 169 $Bq.m^{-3}.h^{-1}$)

    Significant increase of Organic matter-rich rocks Rn-222 production rate (82 to 1201 $Bq.m^{-3}.h^{-1}$)

    No trends observed regarding Rn-222 production rate in Quartz-feldspathic rocks, schists and migmatites, and metagranitoids

    Significant increase of Ra-226 activity in Organic matter-rich rocks (from 24 to 141 Bq/kg)

    Significant increase of Ra-226 activity in Metagranitoids (from 17 to 38 Bq/kg)

    Degree of physical alteration should be included in the assessment of the geogenic radon potential

    Different signature among different rock types

Thank you for your attention!

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Background image: http://nowthatsnifty.blogspot.com/2010/05/20-cool-rocks-and-rock-formations.html?m=1.

R_s – Spearman rank correlation coefficient