THE NATURAL RADIOACTIVITY MAP OF UMBRIA (ITALY): A MULTIPURPOSE TOOL FOR ENVIRONMENTAL UNDERSTANDING

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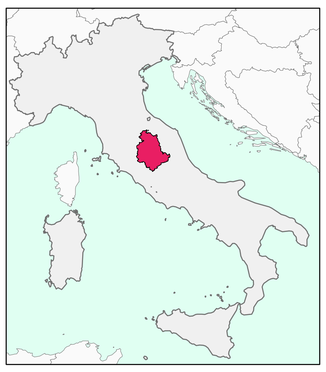


Normalized estimation errors (%)

Total specific activity

Percentile	Bq/kg
100	1553
97	538
80	361
60	314
50	288
40	248
25	156
10	95
0	36

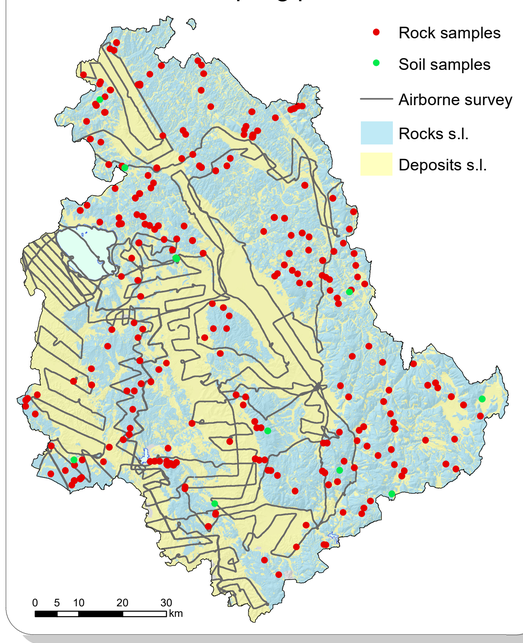
1:150000 scale

0 2.5 5 10 15 km

San Giustino, Città di Castello, Monte Santa Maria Tiberina, Pietralunga, Scheggia e Pascelupo, Costacciaro, Gubbio, Sigillo, Fossato di Vico, Umbertide, Gualdo Tadino, Lisciano Niccone, Tuoro sul Trasimeno, Passignano sul Trasimeno, Trasimeno Lake, Castiglione del Lago, Magione, Corciano, PERUGIA, Valfabbrica, Nocera Umbra, Assisi, Bastia Umbra, Valtopina, Torgiano, Bettona, Cannara, Spello, Deruta, Foligno, Bevagna, Gualdo Cattaneo, Montefalco, Sellano, Preci, Trevi, Piegaro, Città della Pieve, Montegabbione, Monteleone d'Orvieto, Marsciano, Collazzone, Fabro, Parrano, San Venanzo, Fratta Todina, Monte Castello di Vibio, Giano dell'Umbria, Castel Ritaldi, Campello sul Clitunno, Cerreto di Spoleto, Norcia, Allerona, Todi, Massa Martana, Vallo di Nera, Spoleto, Castel Viscardo, Sant'Anatolia di Narco, Cascia, Scheggino, Poggiodomo, Orvieto, Castel Giorgio, Porano, Acquasparta, Monteleone di Spoleto, Baschi, Montecchio, Avigliano Umbro, Montecastrilli, Ferentillo, Guardea, San Gemini, Montefranco, Arrone, Polino, Alviano, Lugnano in Teverina, TERNI, Amelia, Narni, Piediluco Lake, Attigliano, Giove, Penna in Teverina, Stroncone, Otricoli, Calvi dell'Umbria

This map presents the distribution of the **terrestrial natural radioactivity** of the Umbria region (Italy). The total specific activity due to the presence of ^{40}**K**, ^{232}**Th** and ^{238}**U** in the environment is given in Bq/kg. Natural radioactivity was characterized by means of gamma spectroscopy measurements performed by adopting complementary survey methodologies, namely **rock** and **soil sampling**, together with **airborne gamma ray surveys**. Referring to the Geological Database provided by the Geological Regional Service and based on a 1:10000 scale survey, the **214 Cartographic Units** (CUs) were divided into two groups: **Deposits sensu lato (s.l.)**, comprising the 118 CUs corresponding to quaternary deposits and loose geological formations, and **Rocks s.l.**, consisting of 96 CUs of rocky geological formations. The Rocks s.l. group (50% of the regional surface) was investigated via a rock sampling campaign (**one sample per 15 km^2**). The natural radionuclides content of the **283 rock samples** (from representative outcrops) and **14 soil samples** was characterized through high-resolution gamma spectroscopy measurements carried out in laboratory with the **MCA_Rad**, a **High-Pure Germanium** detector that can automatically measure 24 samples without human intervention. The radioactivity of the Deposits s.l. group (50% of the regional surface) was investigated through airborne gamma ray spectroscopy measurements, performed at a nominal 100 m altitude with a **16L volume sodium iodide (NaI)** detector mounted on the **Radgyro**, an **experimental aircraft** devoted to multiparametric surveys. This thematic map represents one of the final products of the **Umbria-Rad project**, realized thanks to the support of the **Italian National Institute of Nuclear Physics** (INFN) and the **Geological Service of the Umbria Region**.

Sampling points



Mean and 1σ uncertainty (symmetric or asymmetric) of K (%), Th (μg/g) e U (μg/g) abundances for the 29 CUs characterized by 3 or more samples and covering 92% of the Rocks s.l. group surface. The distribution function for each dataset was graphically studied using univariate statistics to gain an insight into the data structure and to discriminate the normal and lognormal distributions.

		# samples	K ± σ [%]	Th ± σ [μg/g]	U ± σ [μg/g]
MONTI VULSINI SUPERSYNTHEM *(middle Pleistocene) [Volcanic rocks]*					
ORV1	*Orvieto* Synthem, *Canonica-Torre San Severo* Subsynthem	3	1.54 ± 0.42	82.1 ± 16.7	8.6 ± 1.7
TUSCAN UNITS *(lower Eocene to lower Miocene) [Terrigenous and carbonatic sedimentary rocks]*					
MAC3	*Macigno, Lippiano* Member	7	1.88 ± 0.55	9.4 ± 1.3	2.6 ± 0.6
MAC2	*Macigno, Poggio Belvedere* Member	11	$1.89^{+0.43}_{-0.35}$	$10.2^{+2.2}_{-1.8}$	$2.8^{+0.4}_{-0.3}$
MAC1	*Macigno, Molin Nuovo* Member	6	2.03 ± 0.20	10.7 ± 3.1	2.2 ± 0.8
STO4b	*Scaglia Toscana, Calcareniti di Dudda Member* (litofacies di *Poggioni*)	3	0.70 ± 1.13	5.0 ± 7.5	1.3 ± 0.4
MONTE RENTELLA SUCCESSION *(lower Miocene) [Terrigenous sedimentary rocks]*					
REN	*Montagnaccia* Fm.	15	$1.43^{+0.77}_{-0.50}$	$7.6^{+3.5}_{-2.4}$	$2.4^{+0.7}_{-0.5}$
FMR	*Monte Rentella* Fm.	3	1.86 ± 0.17	10.4 ± 2.1	3.3 ± 0.5
UMBRO-ROMAGNA SUCCESSION (*lower to middle Miocene) [Marls and sandstones]*					
SMT3	*Monte S. Maria Tiberina* Fm., *Poggio Strada* Member	3	1.59 ± 0.27	8.5 ± 1.0	2.8 ± 0.2
FMA9a	*Marnoso-Arenacea Romagnola* Fm., *Civitella* Member	5	1.63 ± 0.23	8.1 ± 0.9	3.0 ± 0.3
FMA4a	*Marnoso-Arenacea Romagnola* Fm., *Galeata* Member (lower litofacies)	3	1.43 ± 0.13	6.1 ± 1.2	2.5 ± 0.5
FMA4b	*Marnoso-Arenacea Romagnola* Fm., *Galeata* Member (litofacies superiore)	31	$0.98^{+1.26}_{-0.55}$	$4.9^{+5.3}_{-2.5}$	$2.0^{+1.1}_{-0.7}$
FMA4b-OLI	*Marnoso-Arenacea Romagnola* Fm., *Galeata* Member (olistostrome)	3	0.94 ± 0.67	5.3 ± 2.7	1.9 ± 0.8
MUM4b	*Marnoso-Arenacea Umbra* Fm., *Bettona* Member (sandy lithofacies)	3	1.98 ± 0.07	6.3 ± 1.3	1.2 ± 0.2
MUM3	*Marnoso-Arenacea Umbra* Fm., *Vesina* Member	4	1.06 ± 0.62	5.0 ± 3.1	1.9 ± 0.7
MUM2	*Marnoso-Arenacea Umbra* Fm., *Monte Casale* Member	3	2.07 ± 0.49	5.9 ± 2.8	1.9 ± 1.4
MUM1	*Marnoso-Arenacea Umbra* Fm., *Casa Sperta*g*lia* Member	8	1.61 ± 0.38	7.8 ± 2.1	2.5 ± 0.6
MUM1c	*Marnoso-Arenacea Umbra* Fm., *Casa Sperta*g*lia* Member (litofacies c)	3	1.20 ± 0.63	6.7 ± 3.5	2.9 ± 0.7
SCH	*Marnoso-Arenacea Umbra* Fm., *Schlier*	4	1.17 ± 0.53	5.9 ± 3.2	2.4 ± 0.8
UMBRO-MARCHEAN SUCCESSION *(upper Triassic to lower Miocene) [Marls and limestones]*					
BIS	*Bisciaro*	5	0.72 ± 0.35	4.4 ± 1.9	2.0 ± 1.0
SCC	*Scaglia Cinerea*	9	0.51 ± 0.20	2.6 ± 1.2	0.7 ± 0.4
VAS	*Scaglia Variegata*	4	0.67 ± 0.13	3.9 ± 0.9	1.0 ± 0.3
SAA	*Scaglia Rossa*	30	$0.19^{+0.31}_{-0.12}$	$1.2^{+1.4}_{-0.6}$	$0.3^{+0.3}_{-0.2}$
SBI	*Scaglia Bianca*	6	0.29 ± 0.53	1.5 ± 1.9	0.6 ± 0.9
FUC	*Marne a Fucoidi*	12	$0.32^{+0.68}_{-0.22}$	$1.5^{+2.4}_{-0.9}$	$0.4^{+0.4}_{-0.2}$
MAI	*Maiolica*	18	$0.09^{+0.08}_{-0.04}$	$0.5^{+0.2}_{-0.2}$	$0.3^{+0.2}_{-0.1}$
CDU	*Calcari Diasprigni*	3	0.15 ± 0.09	0.7 ± 0.3	0.4 ± 0.3
RSA	*Rosso ammonitico*	4	1.08 ± 1.11	3.0 ± 3.1	0.6 ± 0.5
COI	*Corniola*	10	$0.04^{+0.10}_{-0.03}$	$0.6^{+0.2}_{-0.2}$	$0.4^{+0.2}_{-0.1}$
MAS	*Calcare Massiccio*	14	$0.03^{+0.07}_{-0.02}$	$0.5^{+0.3}_{-0.2}$	$0.4^{+0.4}_{-0.2}$

A **multivariate geostatistical method (Collocated CoKriging)** was applied for interpolating sparse gamma-ray data by taking into account the well-known geological information as ancillary variable. The resulting total specific activity map reports the **estimation errors** (in %). This regional radioactivity map is a powerful tool for (i) the identification of distinctive lithological characteristics on the basis of radioactive content; (ii) the definition of the natural baseline of outdoor effective dose rate in the event of a radiological contamination; (iii) the potential assessment of green building indoor air quality through the estimation of the radon flux deriving from uranium content; (iv) the radiological characterization of building materials extracted from quarries in the investigated area.

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