Using $^{222}Rn/^{220}Rn$ versus $^{226}Ra/^{232}Th$ activity ratio and CO_2 concentration in soil gas to trace advective fluxes

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RESEARCH FOCUS

Soil radon transport along fault systems where deep fluids uprise

DISCRIMINATION OF SOIL RADON TRANSPORT

- Measurement of soil gas concentrations of ^{222}Rn and ^{220}Rn at 80 cm depth;
- $^{222}Rn/^{220}Rn$ activity ratio ($t_{1/2}$ very different);
- Evaluation of seasonal soil ^{222}Rn fluctuations;
- ^{226}Ra and ^{232}Th contents in soil;
- $^{222}Rn/^{220}Rn$ versus $^{226}Ra/^{232}Th$ activity ratio;
- Measurement of soil CO_2 concentrations at 80 cm depth (main radon carrier gas);
- Determination of enrichment coefficient of radon;

SOIL RADON CONCENTRATION

- Geological subsurface nature
  (particle size, mineralogical composition, parent elements)
- Soil gas permeability
- Meteo-climatic parameters
- <u>Presence of faults, fractures or deep fluid uprise</u>

SOIL RADON TRANSPORT

DIFFUSIVE

(Fick's law)

$$f = -D \cdot \frac{dC}{dZ}$$

f = diffusive flow intensity ($cm^3 cm^{-2} s^{-1}$);
D = molecular diffusion coefficient ($cm^2\ s^{-1}$);
dC= gas concentration change in the system (m^3/m^3) along a length *dz* (m).

Radon source in the vicinity of the measurement point

$^{222}Rn/^{220}Rn \ll {}^{226}Ra/^{232}Th$

ADVECTIVE

(Darcy's law)

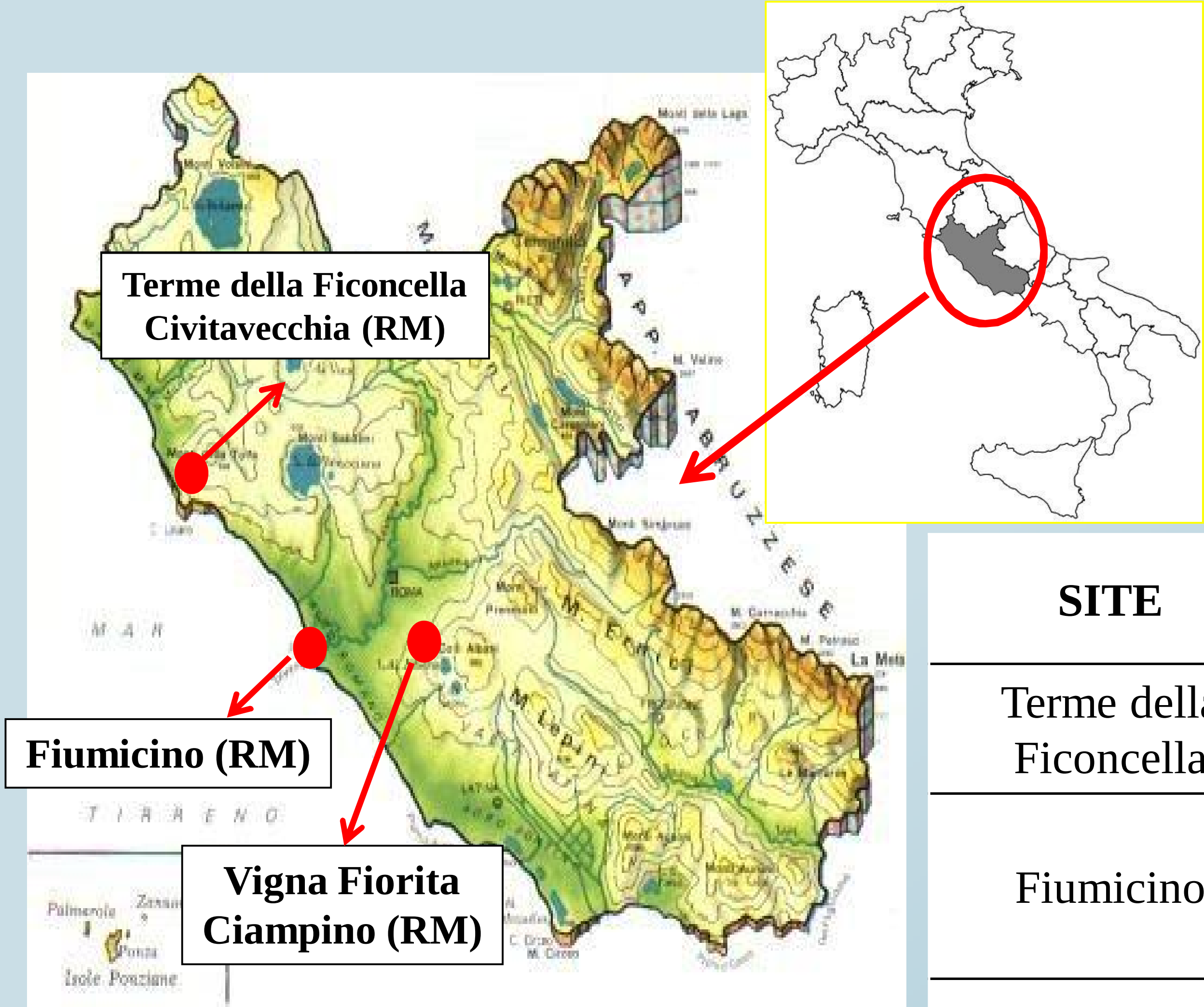
$$v = k \cdot \frac{(-\Delta p + \gamma_g)}{\mu}$$

v = gas velocity ($cm\ s^{-1}$);
k = permeability (m^2);
Δp = pressure variation along a vertical *z* (m);
μ = gas dynamic viscosity ($kg\ m\ s^{-1}$);
ρ_g = gas density ($kg\ m^{-3}$).

Deep Radon source

$^{222}Rn/^{220}Rn > {}^{226}Ra/^{232}Th$

GEOLOGICAL SETTING



Lazio (Italy)

SITE	GEOLOGICAL BEDROCK
Terme della Ficoncella	Travertines and Flysch sediments
Fiumicino	Pleistocene-Holocene sediments (Tiber Delta plain)
Vigna Fiorita	Lahar flows and ignimbrites of the Colli Albani Complex

INSTRUMENTS AND ANALYTICAL METHODS

SOIL GAS CONCENTRATION OF ^{222}Rn AND ^{220}Rn

Radon and thoron activity concentrations (at 80 cm depth): **hollow probe (1)** (Radon v.o.s. corp.) attached (2) to a **drying unit (3)** and to the **continuous radon monitor (4)** (RAD7 Durridge Co.), connected in series.

SOIL CO_2 CONCENTRATION

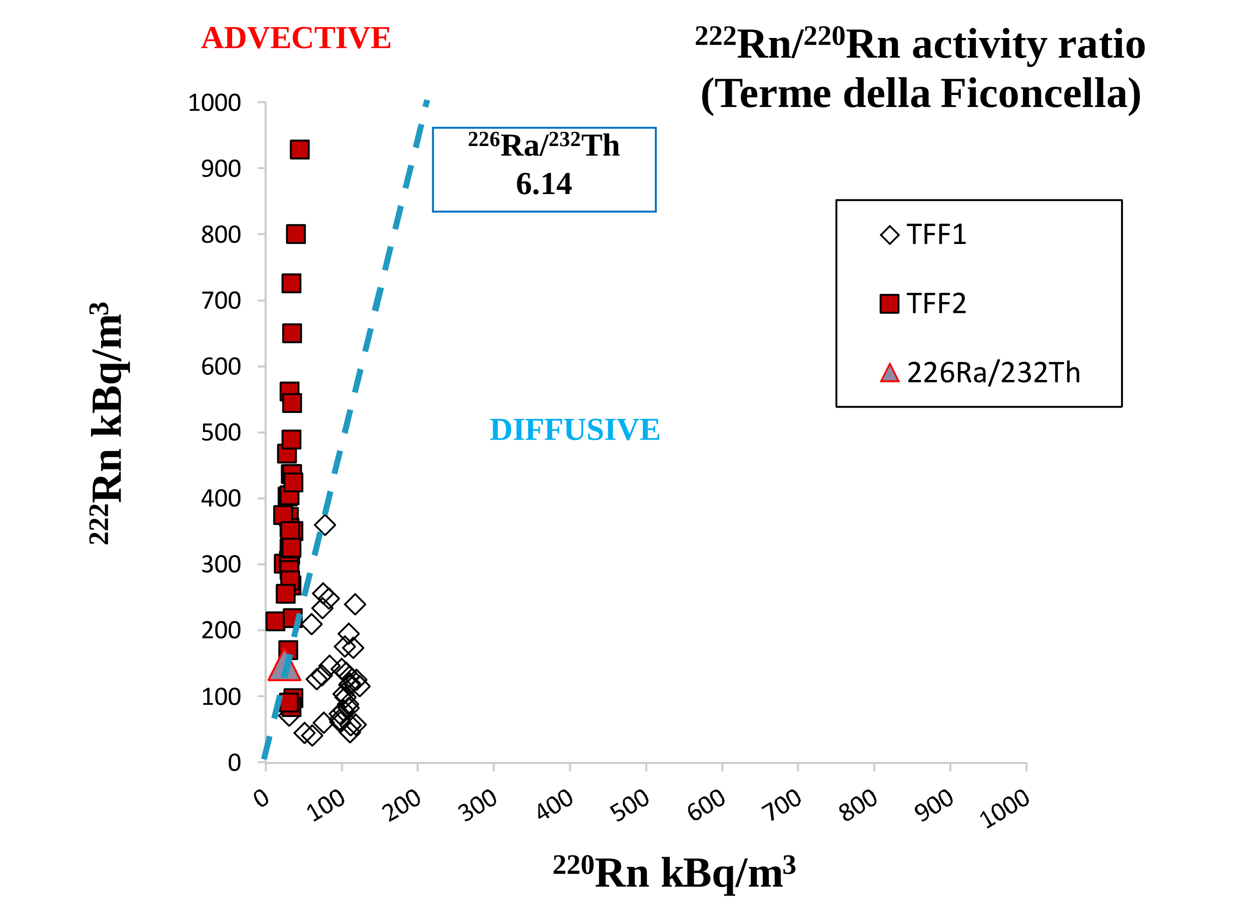
CO_2 concentration (at 80 cm depth): **infrared detector** (Dräger X-am 7000)

^{226}Ra AND ^{232}Th CONTENT IN SOIL

ɔ - spectrometer with Hyper Pure Germanium detector (**HPGe**)

RESULTS FROM TERME DELLA FICONCELLA (CIVITAVECCHIA)

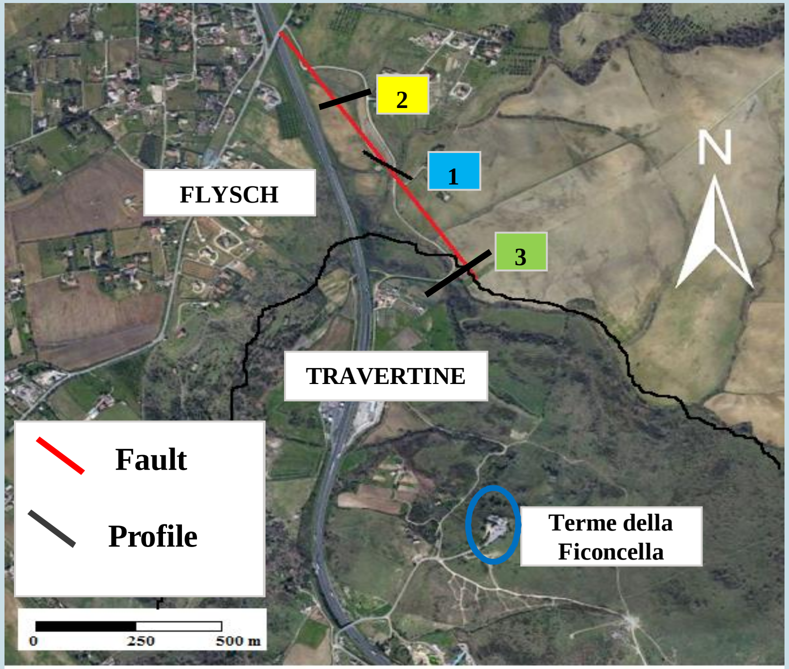
Travertine $^{226}Ra/^{232}Th = 6.14$



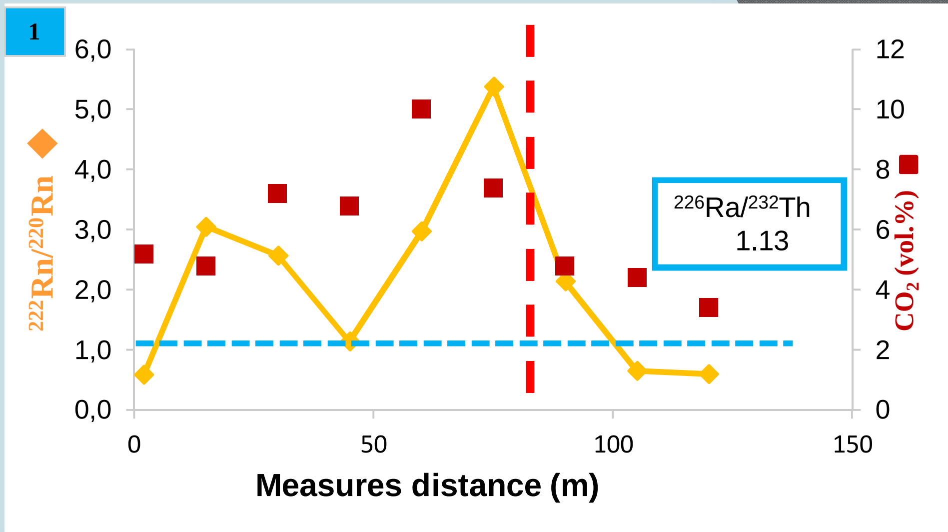
TFF1 and TFF2 permanent station

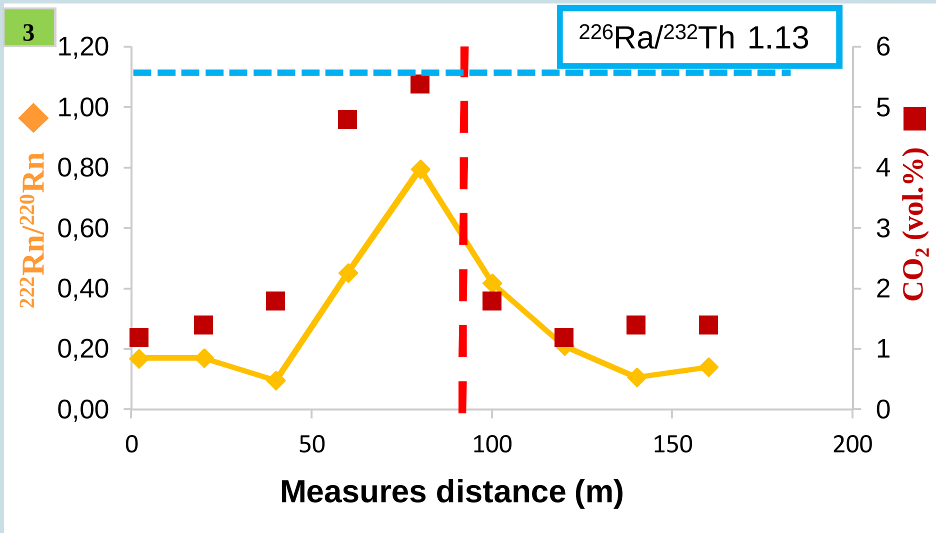
- ✓ Rich soil in ^{226}Ra and poor in ^{232}Th;
- ✓ TFF1: mean CO_2 - 1.6 vol.%;
- ✓ TFF2: mean CO_2 - 2.1 vol.%;
- ✓ TFF1 radon transport *predominantly diffusive;*
- ✓ TFF2 radon transport *diffusive and advective;*

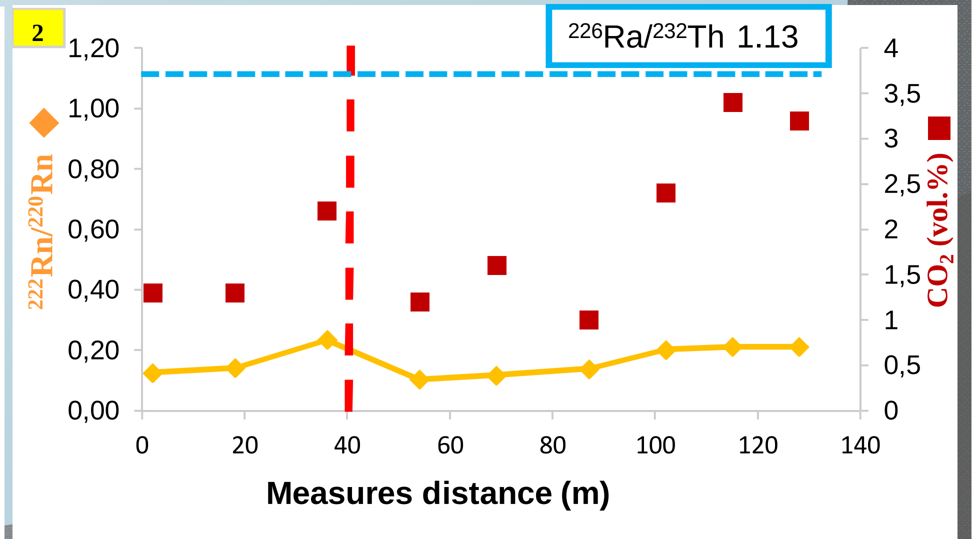
SOIL GAS MEASUREMENTS ACROSS CIVITAVECCHIA FAULT



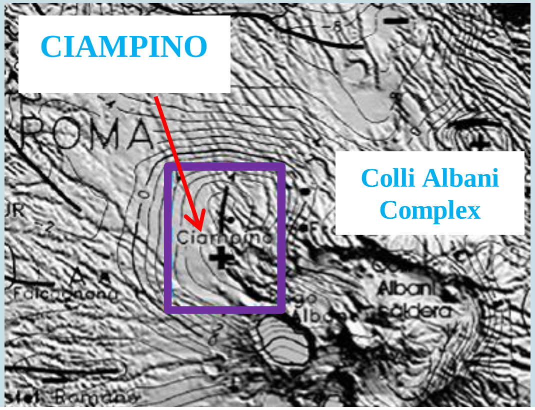
$^{226}Ra/^{232}Th$ Flysch = 1.13





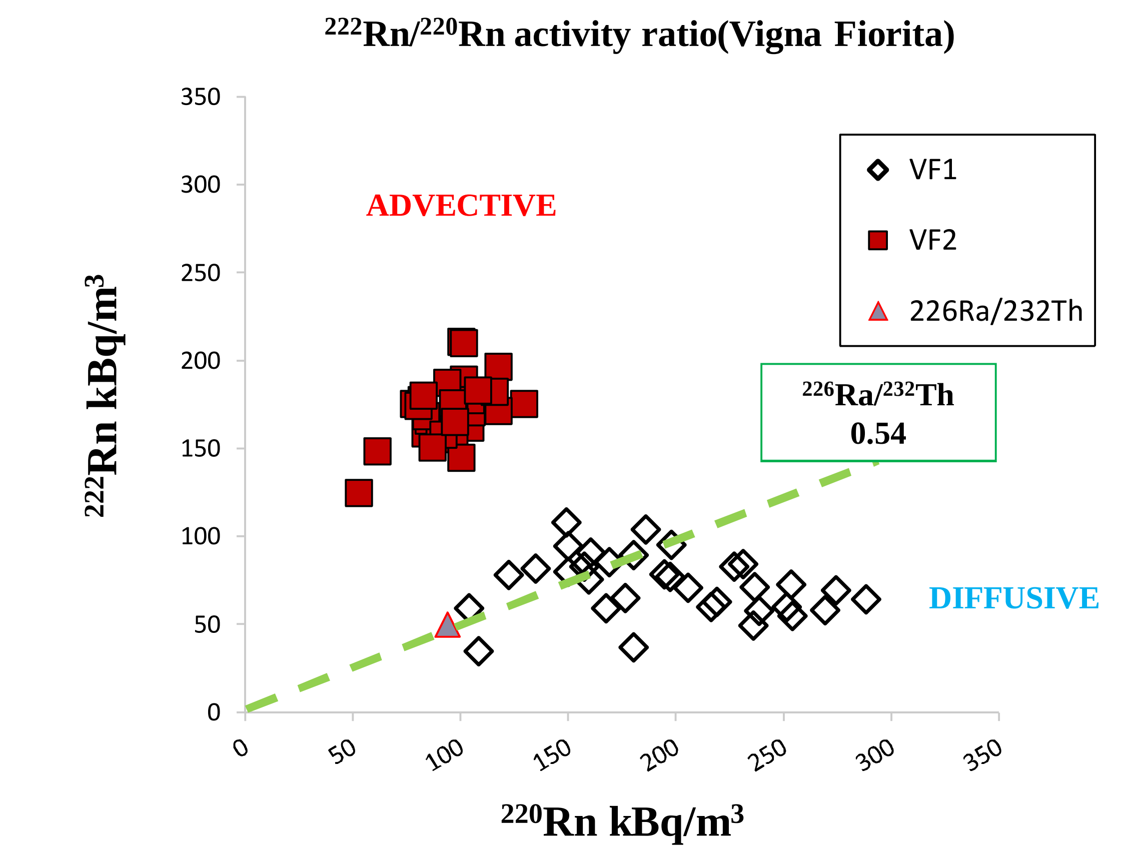


RESULTS FROM VIGNA FIORITA (CIAMPINO)



Degassing of this area occurs at faults of the Ciampino carbonate high that acts as a reservoir for large quantities of gases (primarily composed of CO_2, H_2S and radon) deriving from deep residual magmatic activity. These gases represent a high risk of indoor gas accumulation for the inhabitants of the area.

$^{226}Ra/^{232}Th$ ñVilla Doria Unitò = 0.54



VF1 and VF2 permanent station

✓ significant differences in ^{222}Rn and CO_2 concentrations and in the seasonal variability;

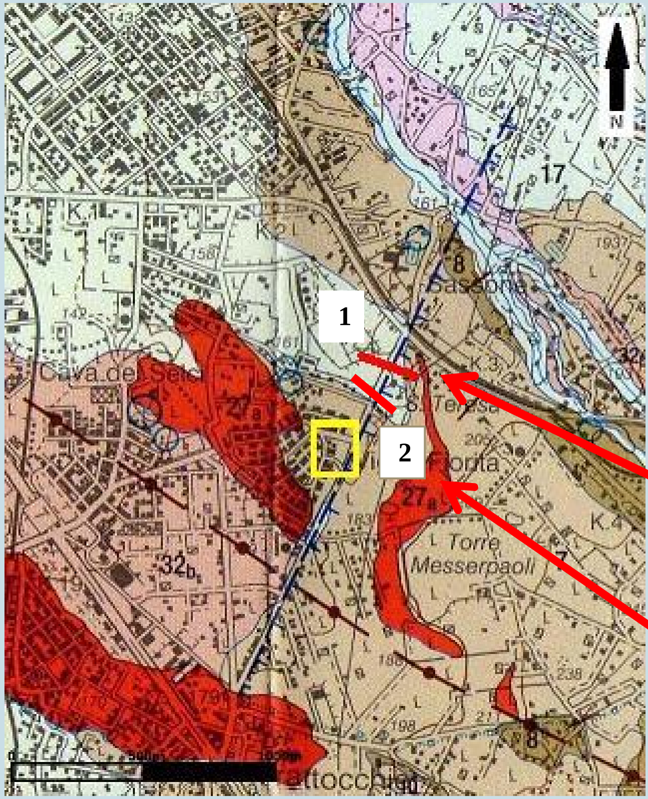
✓ VF1: mean CO_2 - 4.7 vol.%;

✓ VF2: mean CO_2 - 70.1vol.%;

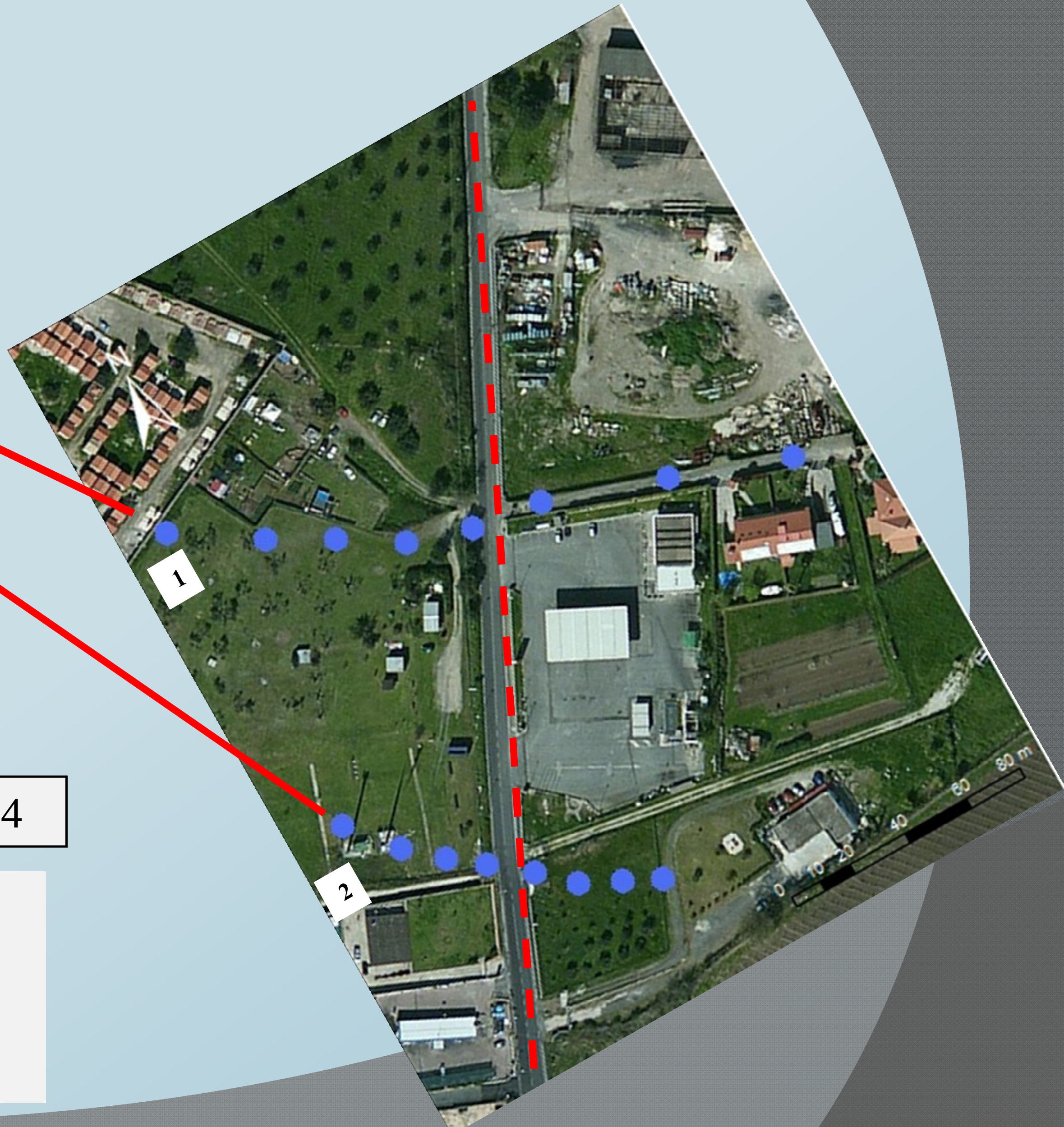
✓ VF1: radon transport *diffusive and advective;*

✓ VF2 radon transport *strictly advective.*

SOIL GAS MEASUREMENTS ACROSS VIGNA FIORITA FAULT



(Giordano et al., 2009)

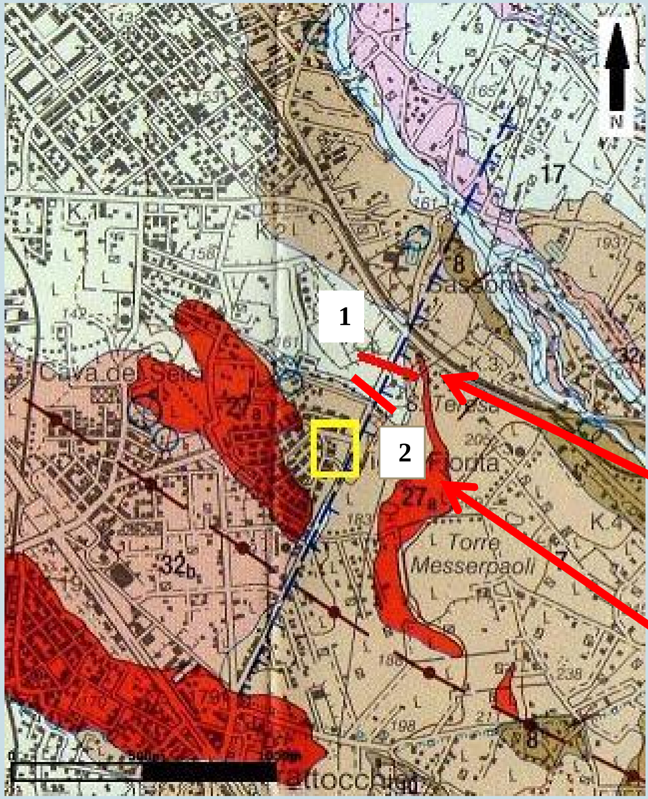


$^{226}Ra/^{232}Th$ ñTavolato Unitò = 1.4

PROFILE 1:
8 measures, 180 m length, 20 m equidistance

PROFILE 2:
8 measures, 100 m length, 15 m equidistance

SOIL GAS MEASUREMENTS ACROSS VIGNA FIORITA FAULT



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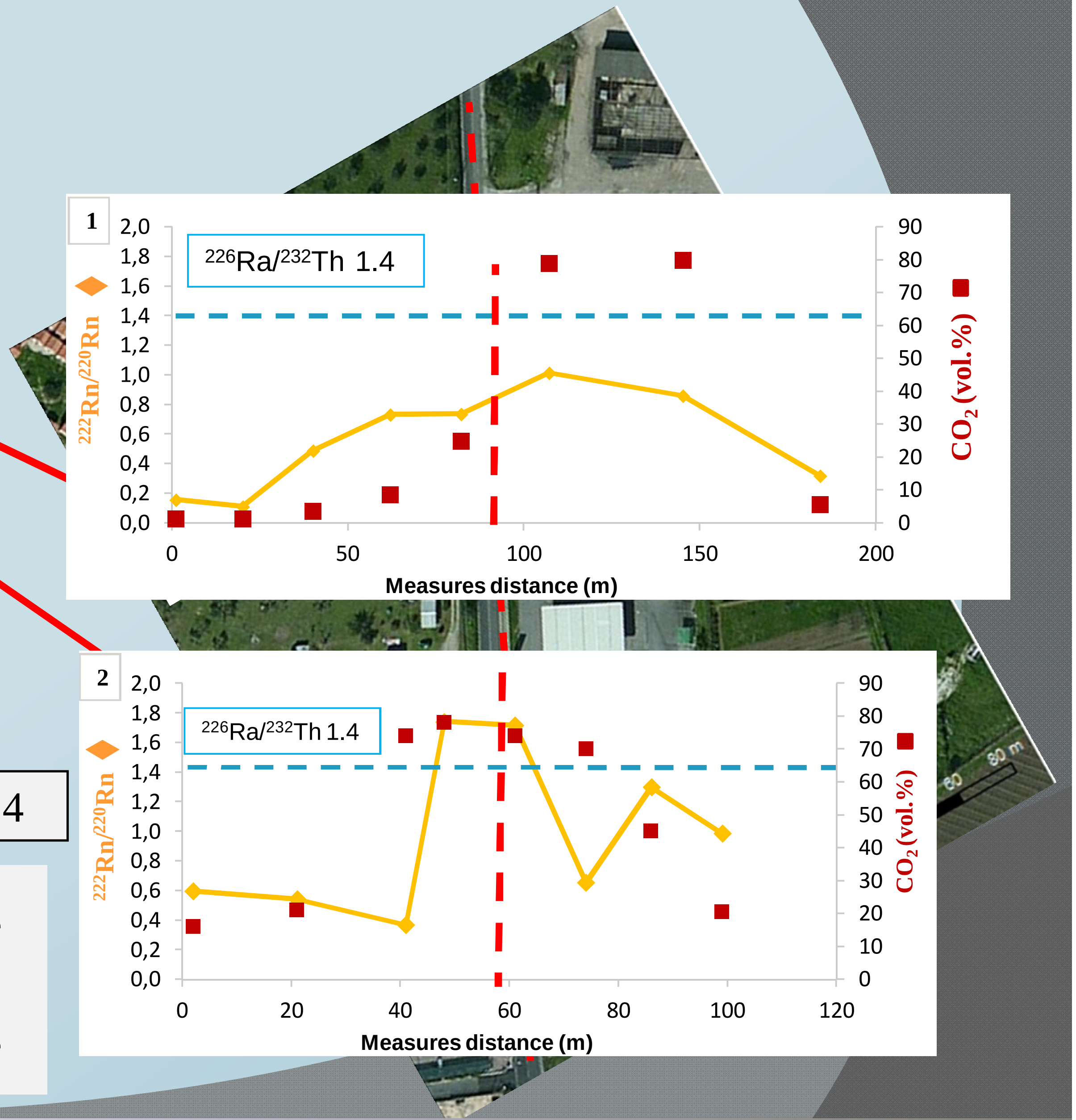
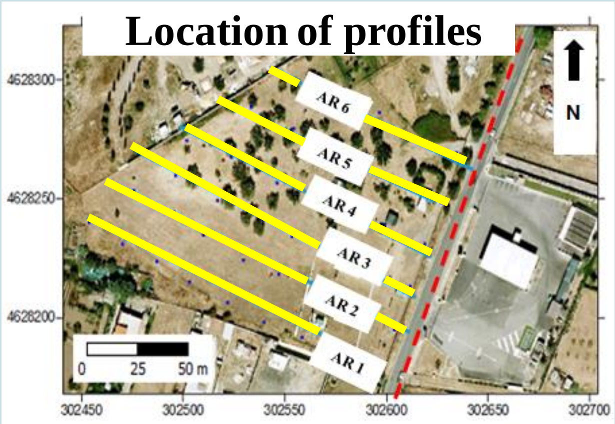
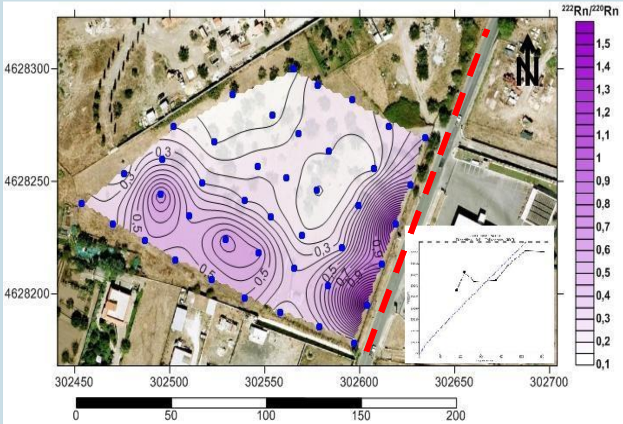


SOIL GAS MEASUREMENTS PROFILES ACROSS VIGNA FIORITA FAULT

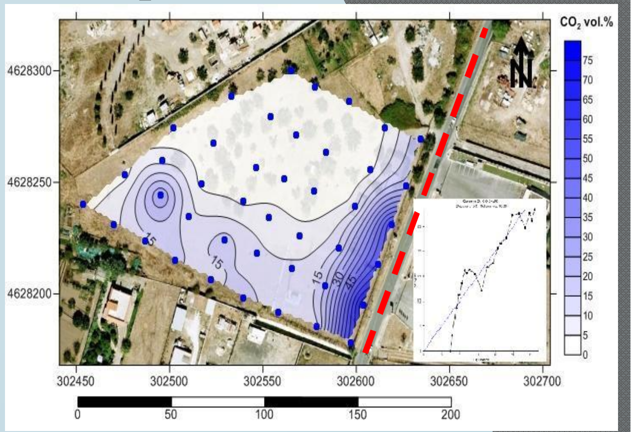
Location of profiles

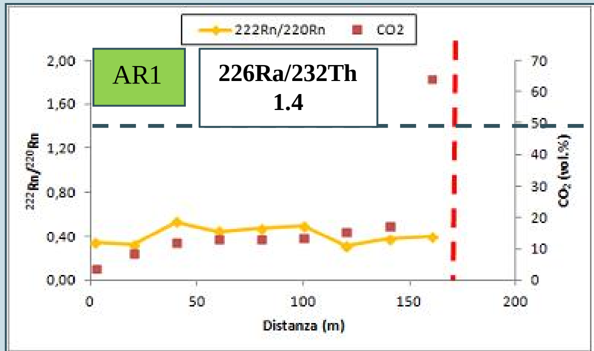


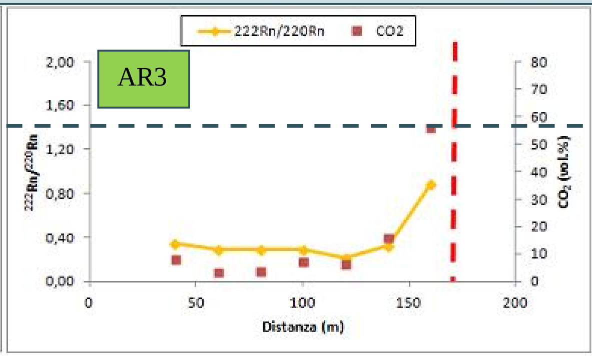
$^{222}Rn/^{220}Rn$ ratio map

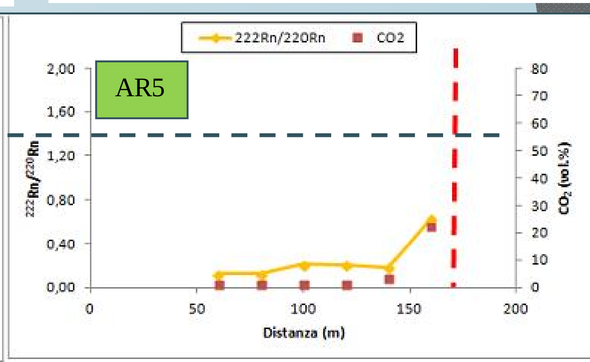


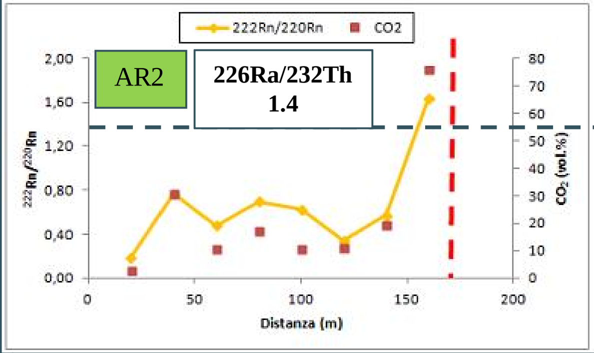
CO_2 concentration map

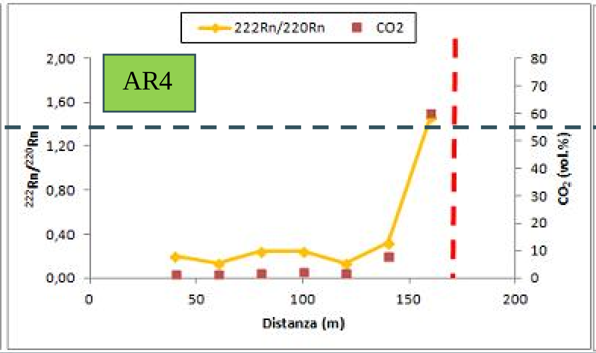


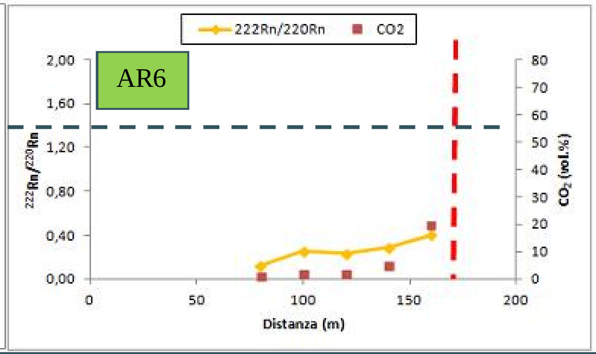






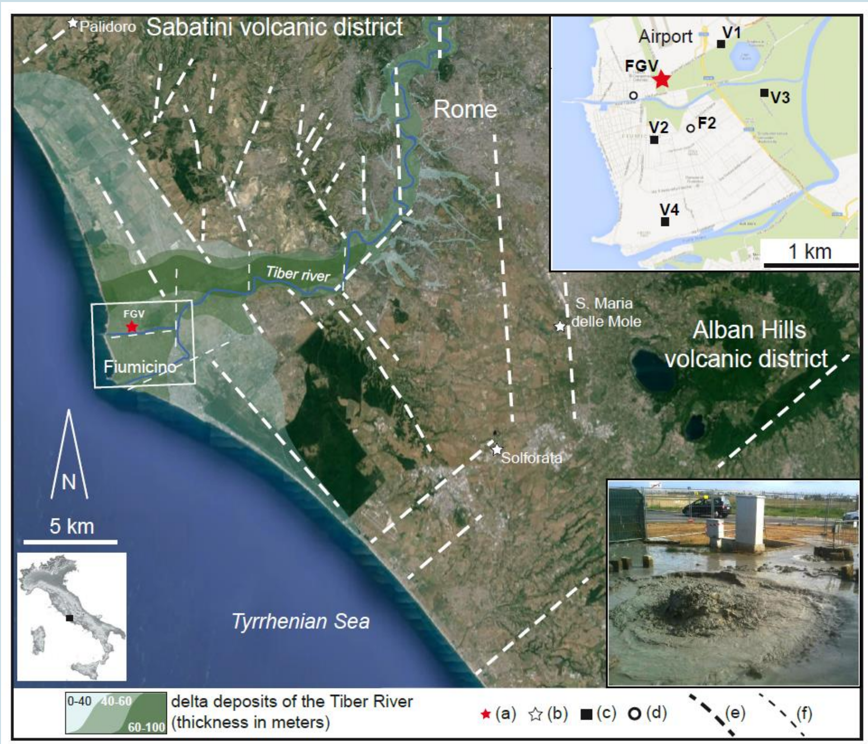




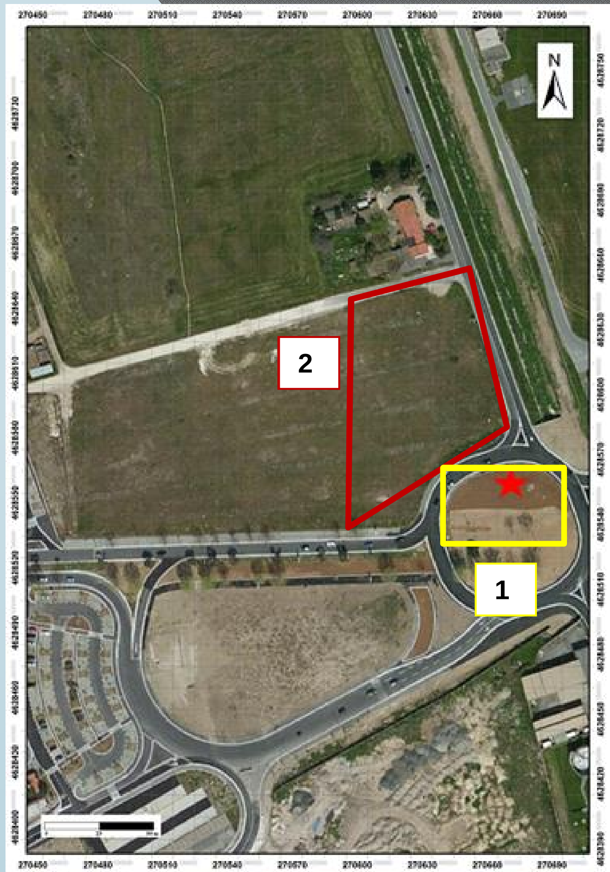


RESULTS FROM FIUMICINO

In the Fiumicino area in August 2013, two boreholes at 35m depth, caused a gas blowout from a pressurized clay-confined gas pocket. Other past events of this type have also been reported in the area with gases mainly composed of CO_2 with traces of CH_4 and H_2S.

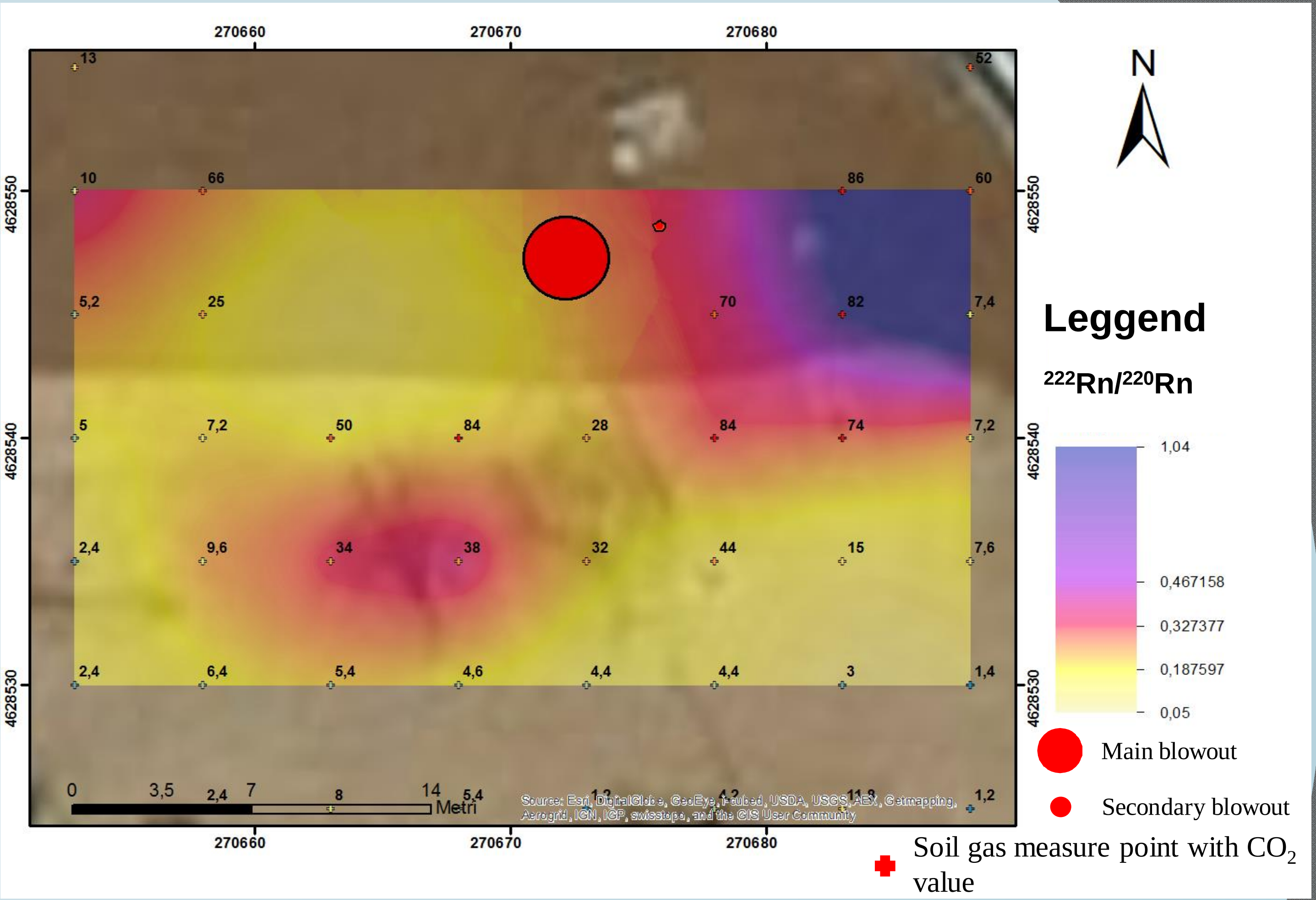


(Ciotoli et al.,2013)



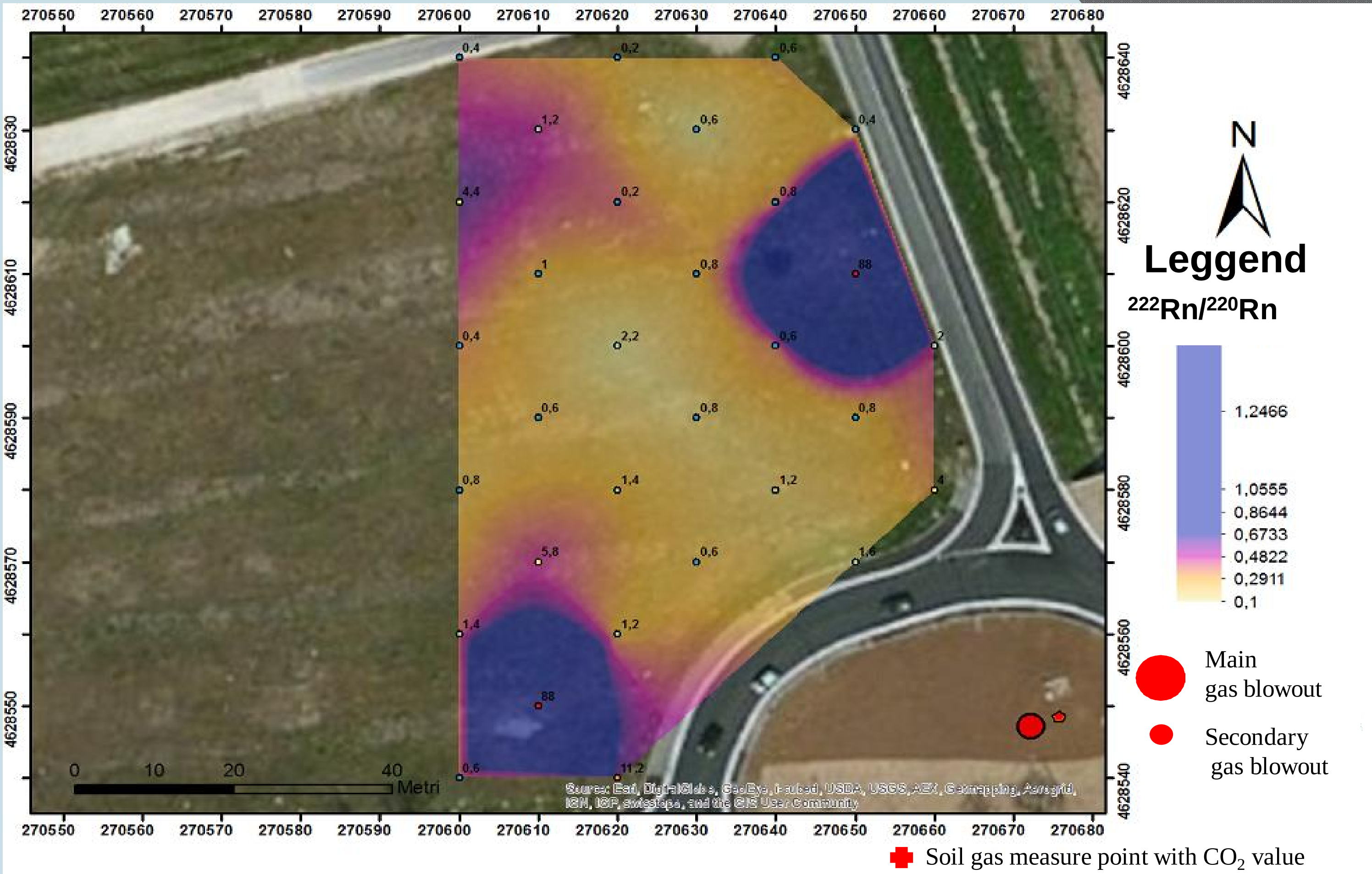
Soil gas measurements have been carried out on active pools in the roundabout (**1**) and on the adjacent area to the north (**2**, called circus land).

$^{222}Rn/^{220}Rn$ MAP VS CO_2 CONCENTRATION IN THE ROUNDABOUT

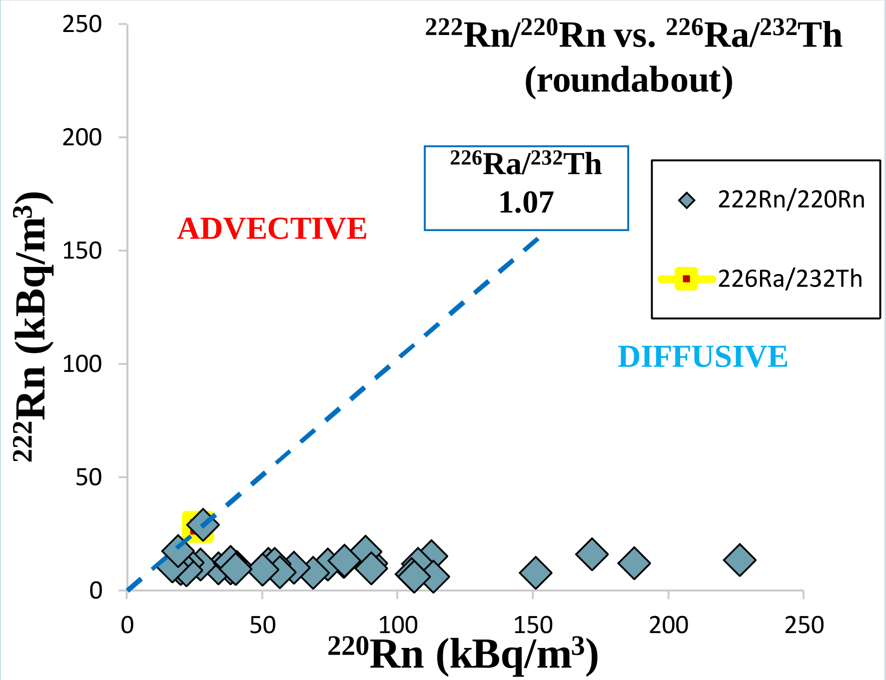


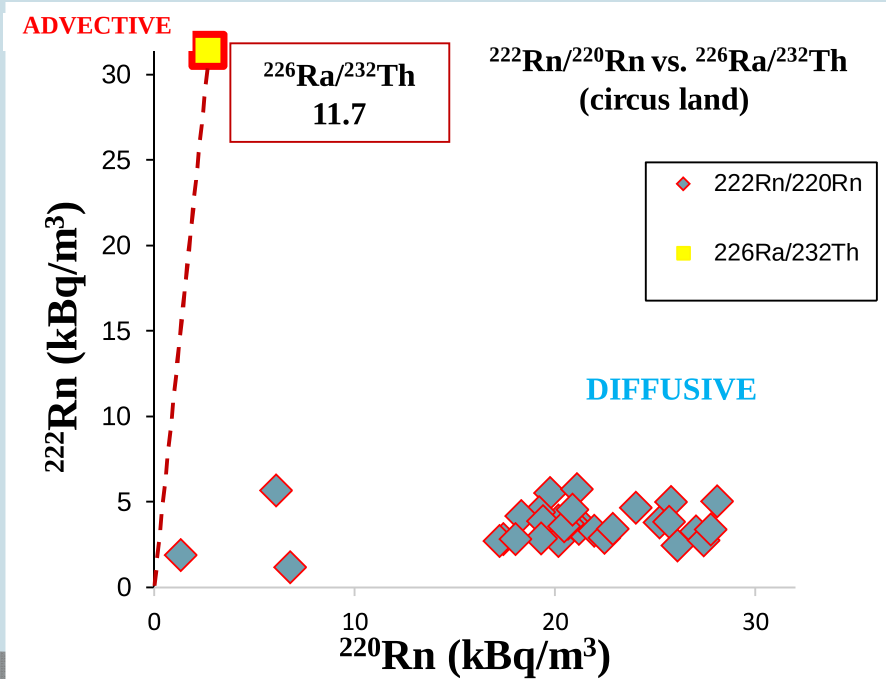
Parameter	Min	Max	Mean	St. dev.
^{222}Rn (Bq/m^3)	6180	29150	11760	4070
$^{222}Rn/^{220}Rn$	0.05	1.04	0.27	0.24
CO_2 (vol.%)	1.6	88	25.9	25.65

$^{222}Rn/^{220}Rn$ MAP VS CO_2 CONCENTRATION IN THE “CIRCUS LAND”



Parameter	Min	Max	Mean	St. dev.
^{222}Rn (Bq/m^3)	1200	5780	3690	1080
$^{222}Rn/^{220}Rn$	0.1	1.45	0.24	0.27
CO_2 (vol.%)	0.2	88	7.22	21.67





RADON TRANSPORT IN THIS AREA

$^{226}Ra/^{232}Th$ Backfill = 1.07 (roundabout)

- ✓ radon transport *mainly diffusive;*
- ✓ some measuring points have *diffusive and advective* mechanism;
- ✓ theese measuring points are located near gas blowout

$^{226}Ra/^{232}Th$ Sand = 11.7 (circus land)

- ✓ radon transport *strictly diffusive;*
- ✓ large disequilibrium between ^{226}Ra and ^{232}Th in the soil;
- ✓ in the three hotspots there is increase in the advective component where the highest soil CO_2 concentrations were recorded.

ASSESSMENT OF ENRICHMENT COEFFICIENT

Generally **Radon Emanation** is the number of atoms of radon leaving the solid material divided by the amount generated from the sample. Where values higher than 0.5 - 0.7 can be used to trace advective fluxes of deep gases (Schuman, 1993).

In this study, we also obtained values greater than 1, which is actually an indication of **Radon Enrichment.**

Enrichment Coefficient

$$E.C. = \frac{C_{222Rn}}{C_{226Ra} \cdot \rho}$$

where:
C_{222Rn} = soil radon activity concentration (Bq/m^3);
C_{226Ra} = soil ^{226}Ra content (Bq/kg);
ρ = soil density (kg/m^3).

ID measurements point	soil ^{222}Rn (Bq/m^3)	^{226}Ra (Bq/kg)	E.C. (ρ 1200 kg/m^3 soil density)	E.C. (ρ 1400 kg/m^3 soil density)	soil CO_2 (vol.%)	Soil Radon transport
VF1 Vigna fiorita*	72000	57.5	1.04	0.89	4.7	*Diffusive-advective mixed*
VF2 Vigna fiorita*	**169880**	**43.0**	**3.29**	**2.82**	**70.1**	***Strictly advective***
TFF1 T. Ficoncella*	128000	91.8	1.18	1.00	1.6	*Diffusive-advective mixed*
TFF2 Ficoncella*	**382270**	**224.1**	**1.42**	**1.22**	**2.1**	***Diffusive-advective mixed***
Roundabout MIN Fiu.	6180	28.1	0.18	0.15	1.6	*Diffusive*
Roundabout MAX Fiu.	29150	28.1	0.86	0.74	88	*Diffusive-advective mixed*
Circus (MIN) Fiu.	1200	31.4	0.03	0.03	0.2	*Diffusive*
Circus (MAX) Fiu.	5780	31.4	0.15	013	88	*Diffusive*

*three years monitoring at permanent stations on a monthly basis

CONCLUDING REMARKS

- **Faults and fractures are preferential pathways for strictly advective ^{222}Rn uprise from deep sources.**

- **Advective movement is favoured by the presence of the carrier gas (CO_2), capable of carrying the radon from deeper to more superficial areas.**

- **For the recognition of deep sources the signal given by the ^{220}Rn is important, as the concentration tends to decrease significantly because of its low half-life.**

- **^{222}Rn/^{220}Rn ratio signal, together with the knowledge of the soil content of ^{232}Th and ^{226}Ra of a given area is a stronger signal than the soil ^{222}Rn concentration on its own.**

- **Evaluation of both the soil gases and its intrinsic permeability are vital for the investigation of unconformities and for risk assessment of indoor environments.**


Thank you for your attention