



**The Abdus Salam
International Centre for Theoretical Physics**



2265-33

**Advanced School on Understanding and Prediction of Earthquakes and
other Extreme Events in Complex Systems**

26 September - 8 October, 2011

**New Methodological Developments in Nuclear Physics for Solid Earth Physics
Part 1 - Part 2**

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Italy*



New Methodological Developments in Nuclear Physics for Solid Earth Physics

Part 1 - Part 2

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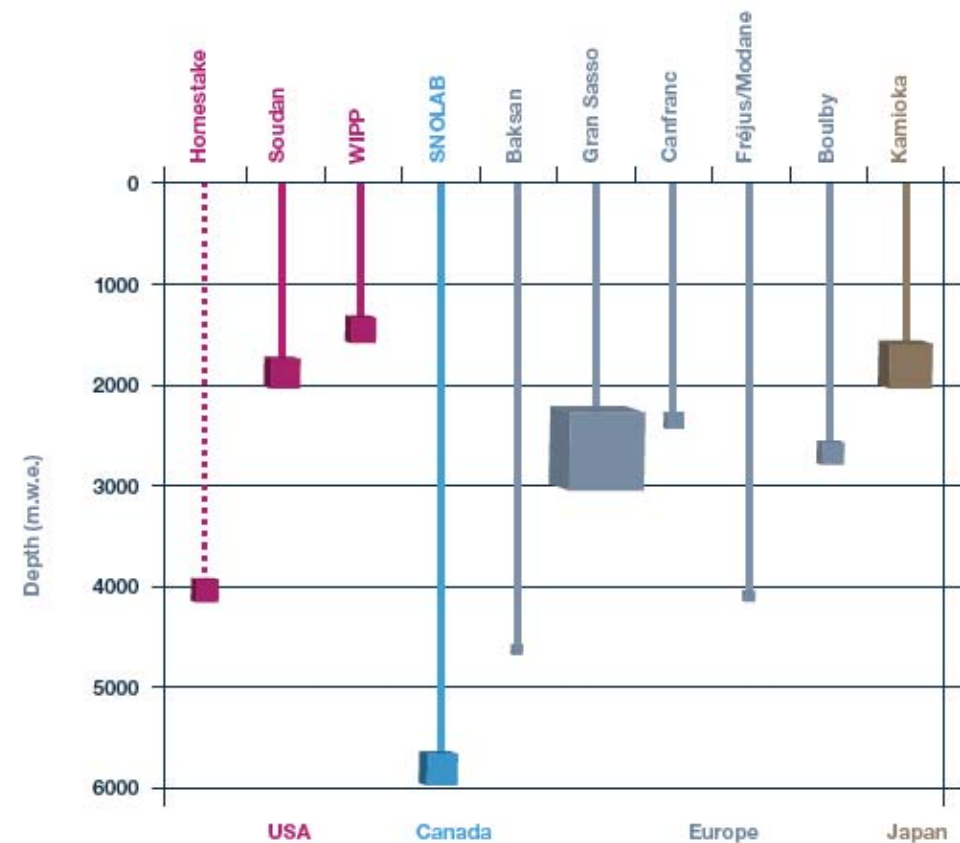


Outline

- Gran Sasso National Laboratory - *Neutrino Physics, Dark Matter,*
- Neutron flux background
- Radon
- Uranium and geodynamic processes in the Earth's Lithosphere and Mantle



Gran Sasso National Laboratory

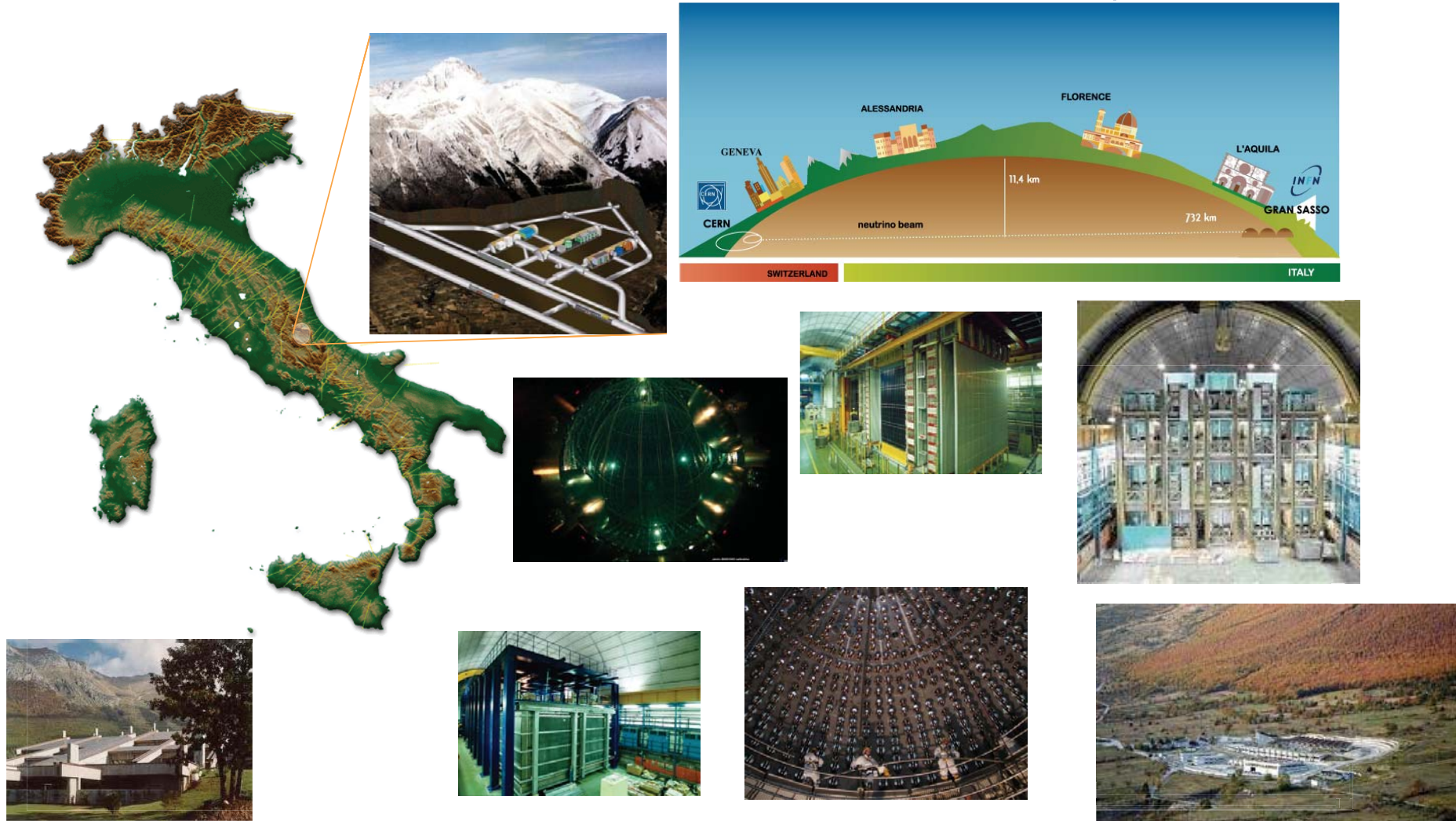




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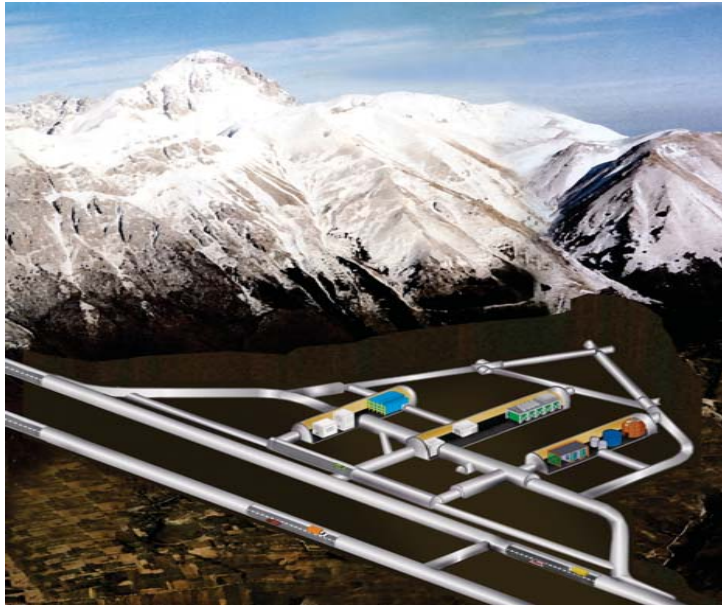
E interval	Neutron Flux ($10^{-6}\text{cm}^{-2}\text{s}^{-1}$)					
(MeV)	Ref. [1]	Ref. [2]	Ref. [3]	Ref. [4]	Ref. [5]	Ref. [6]
$10^{-3} - 0.5$			0.54 ± 0.01			
$0.5 - 1$						
$1 - 2.5$		0.14 ± 0.12	(0.53 ± 0.08)			
$2.5 - 3$		0.13 ± 0.04	0.27 ± 0.14			
$3 - 5$		0.15 ± 0.04	(0.18 ± 0.04)			
$5 - 10$	0.05 ± 0.01		3.0 ± 0.8	0.09 ± 0.06		
	(0.04 ± 0.01)					
$10 - 15$	0.78 ± 0.3	$(0.4 \pm 0.4) \cdot 10^{-3}$	$(0.6 \pm 0.2) \cdot 10^{-3}$			
			$((0.7 \pm 0.2) \cdot 10^{-3})$			
$15 - 25$			$(0.5 \pm 0.3) \cdot 10^{-6}$			
			$((0.1 \pm 0.3) \cdot 10^{-6})$			

Wulandari, H. et al., 2004. Neutron flux at the Gran Sasso underground laboratory revisited. *Astropart. Phys.*, doi:10.1016/j.astropartphys.2004.07.005.

The measurements of the neutron flux made during the years at the LNGS-INFN revealed differences of orders of magnitude

Energy (MeV)	Neutron flux ($10^{-6}\text{cm}^{-2}\text{s}^{-1}$)				
	Measurement in hall A [3]		MC simulations, this work		
	Flat	Flat + Watt Spect.	Hall A, dry	Hall A, wet	Hall C, dry
$0-5 \cdot 10^{-8}$	1.08 ± 0.02	1.07 ± 0.05	0.53 ± 0.36	0.24 ± 0.15	0.24 ± 0.17
$5 \cdot 10^{-8}-10^{-3}$	1.84 ± 0.20	1.99 ± 0.05	1.77 ± 0.45	0.71 ± 0.19	0.93 ± 0.33
$10^{-3}-2.5$	0.54 ± 0.01	0.53 ± 0.08	1.22 ± 0.32	0.57 ± 0.16	0.91 ± 0.32
$(1-2.5)$	$(0.38 \pm 0.01)^a$	$(0.38 \pm 0.06)^{a,b}$	(0.35 ± 0.12)	(0.18 ± 0.06)	(0.27 ± 0.12)
$2.5-5$	0.27 ± 0.14	0.18 ± 0.04	0.18 ± 0.05	0.12 ± 0.04	0.15 ± 0.05
$5-10$	0.05 ± 0.01	0.04 ± 0.01	0.05 ± 0.02	0.03 ± 0.02	0.03 ± 0.01
Total flux	3.78 ± 0.25	3.81 ± 0.11	3.75 ± 0.67	1.67 ± 0.29	2.26 ± 0.49
Flux ($E > 1\text{ MeV}$)	0.70 ± 0.14	0.60 ± 0.07	0.58 ± 0.13	0.33 ± 0.07	0.45 ± 0.13

The neutron flux depends on the humidity of the environment: in hall A is lower if the concrete is wet than if it is dry (8% and 16% water content, respectively). The effect seen in the flux here is caused only by moderation. Wet concrete moderates neutrons more effectively than dry concrete due its higher hydrogen content.



1,400 m of overlaying rock
cosmic μ reduction to $1 \times \text{m}^{-2} \text{h}^{-1}$
underground volume: $180,000 \text{ m}^3$

The natural radioactivity in rock and materials used for the internal structures of the LNGS-INFN has been studied in detail, and the specific activities of natural radionuclides are known with high accuracy for the characterization of neutron background

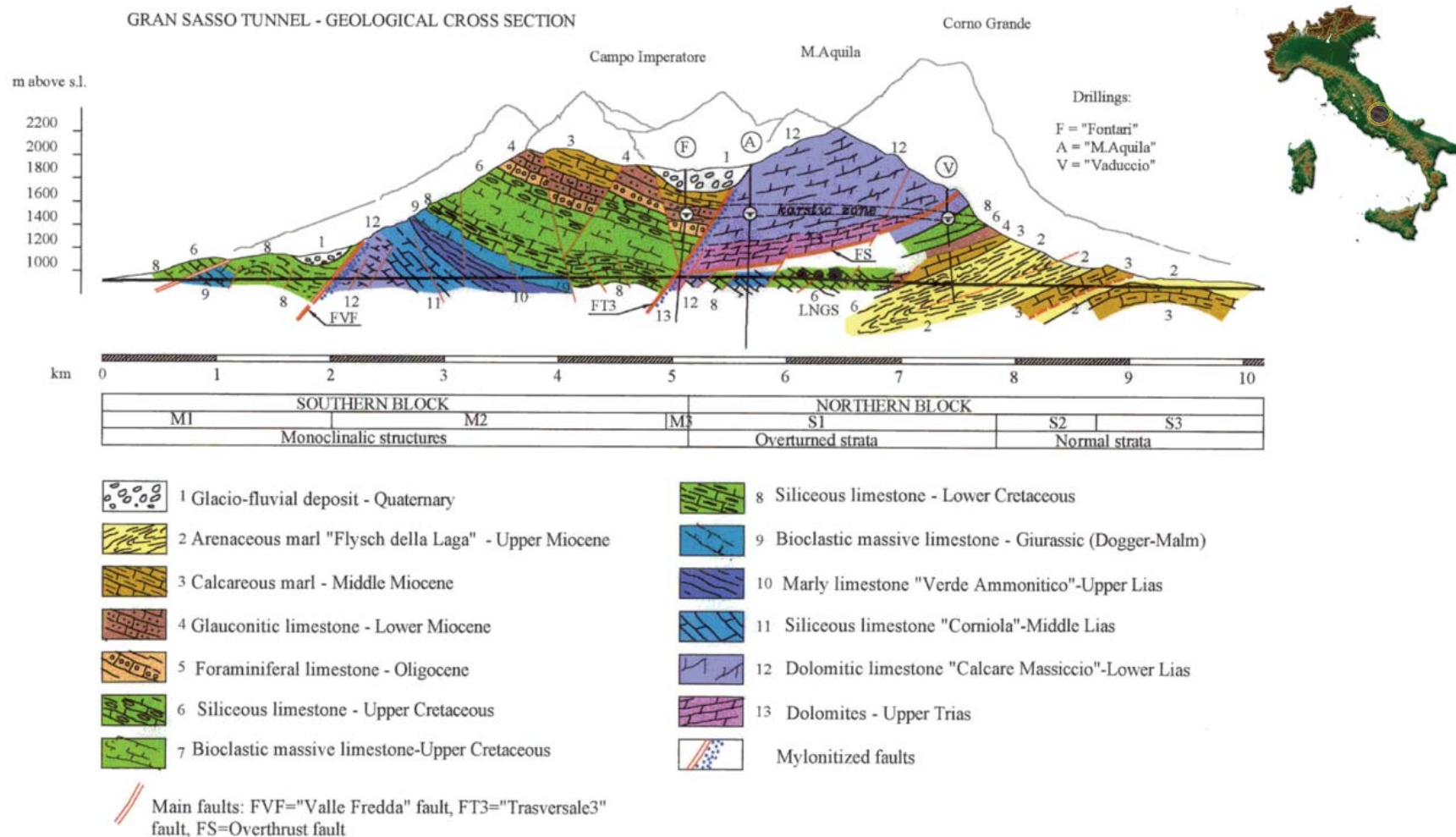
The ^{238}U and ^{232}Th contaminations in concrete are $1.05 \pm 0.12 \text{ ppm}$ and $0.656 \pm 0.028 \text{ ppm}$, respectively.

Esposito, A. and Pelliccioni, M., 1985. Study on natural radioactivity in building materials with a view to the construction of the INFN Laboratory of Gran Sasso. Nucl. Sci. J., 22, 291-295.

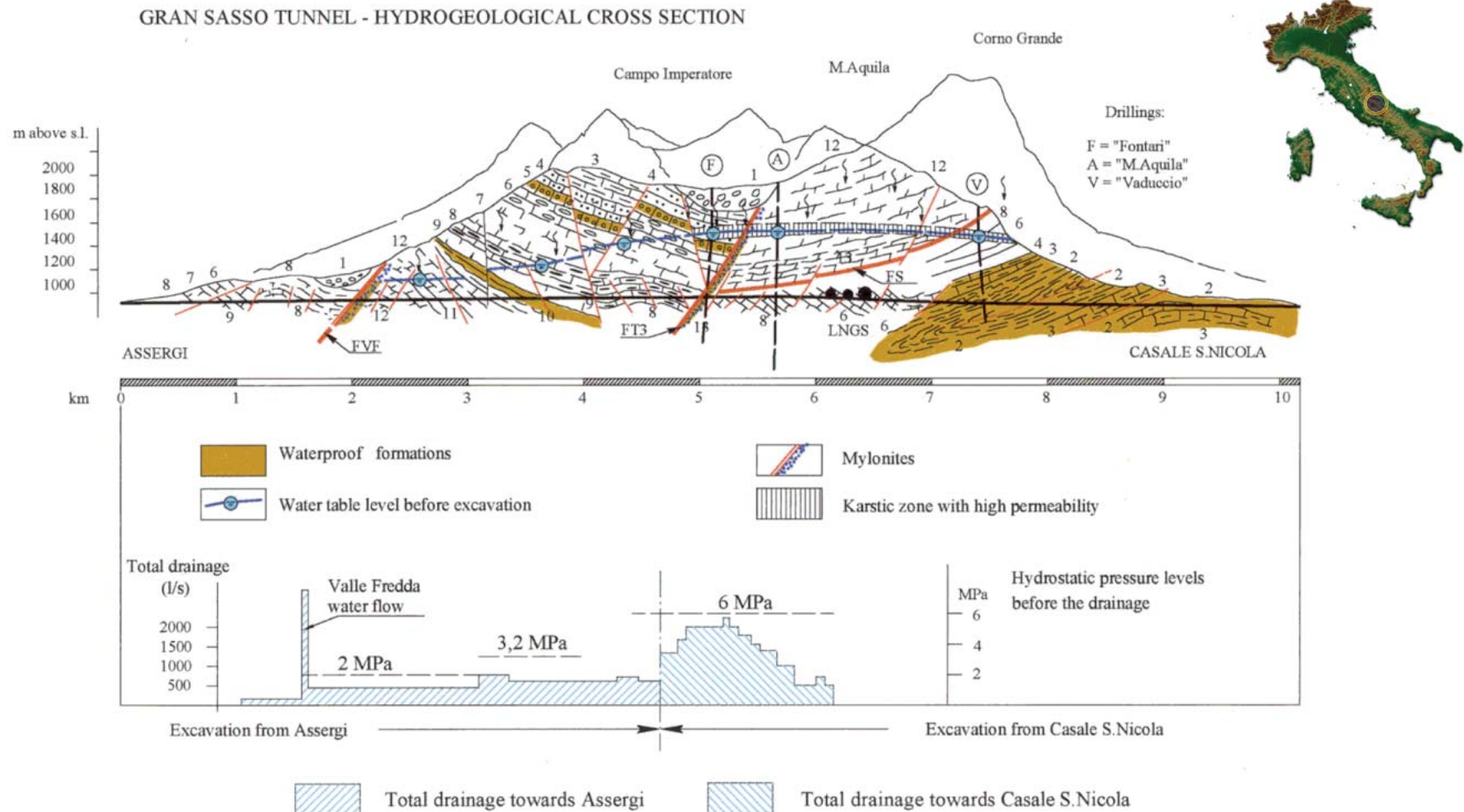
^{238}U and ^{232}Th activities in LNGS rock

Hall	Activities (ppm)	
	^{238}U	^{232}Th
A	6.80 ± 0.67	2.167 ± 0.074
B	0.42 ± 0.10	0.062 ± 0.020
C	0.66 ± 0.14	0.066 ± 0.025

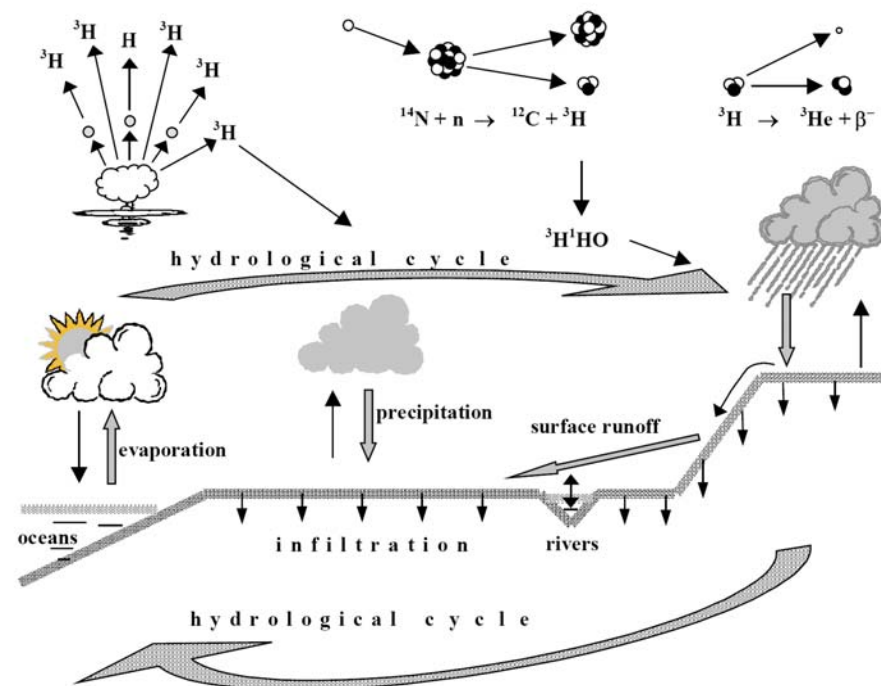
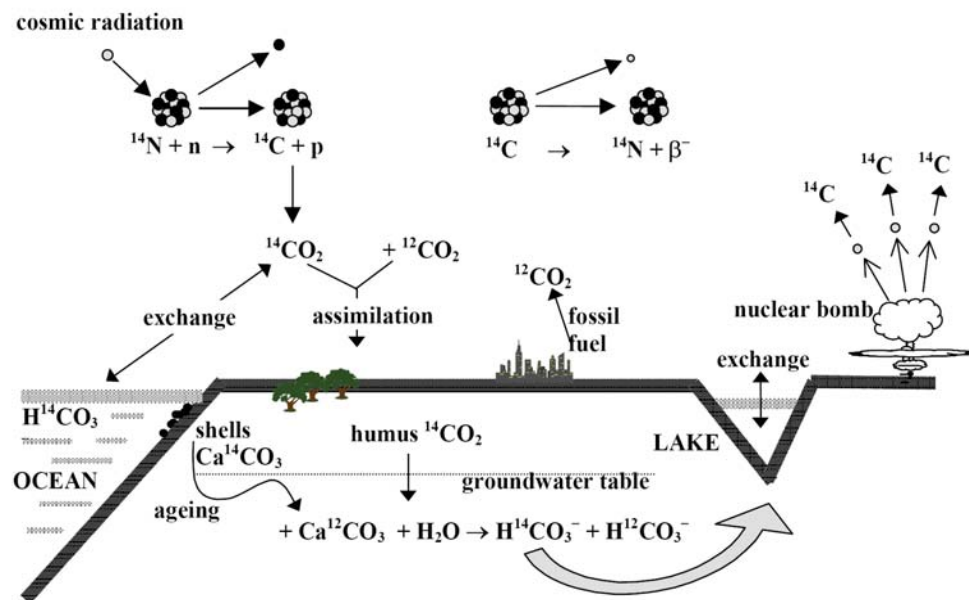
Wulandari, H. et al., 2004. Neutron flux at the Gran Sasso underground laboratory revisited. Astropart. Phys., doi: 10.1016/j.astropartphys.2004.07.005.



Plastino, W., 2006. Monitoring of geochemical and geophysical parameters in the Gran Sasso aquifer. Radionuclides in the Environment, Elsevier, 335-342.



Plastino, W. *et al.*, 2010. Uranium groundwater anomalies and L'Aquila earthquake, 6th April 2009 (Italy). *J. Environ. Radioact.*, 101, 45-50.





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Radiation Measurements

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Tritium in water electrolytic enrichment and liquid scintillation counting

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Abstract

A batch of electrolysis cells was developed for tritium in water samples enrichment by at least a factor 10. The cell batch is controlled by a pre-programmable electronic system that interrupts the current through any cell when the planned electrolyte volume is attained. A starting and a final distillation of water samples are carried out before and after the electrolytic enrichment. Both distillations are made to dryness in order to avoid isotopic fractionation.

A second electrolysis step allowed the tritium enrichment factor (EFT) to be doubled. The EFT was calculated by means of the deuterium enrichment factor (EDF) that was measured by mass spectrometry. The EFT was also measured by liquid scintillation counting. The calculated and measured EFT values were found in good agreement, especially for samples with significant tritium content.

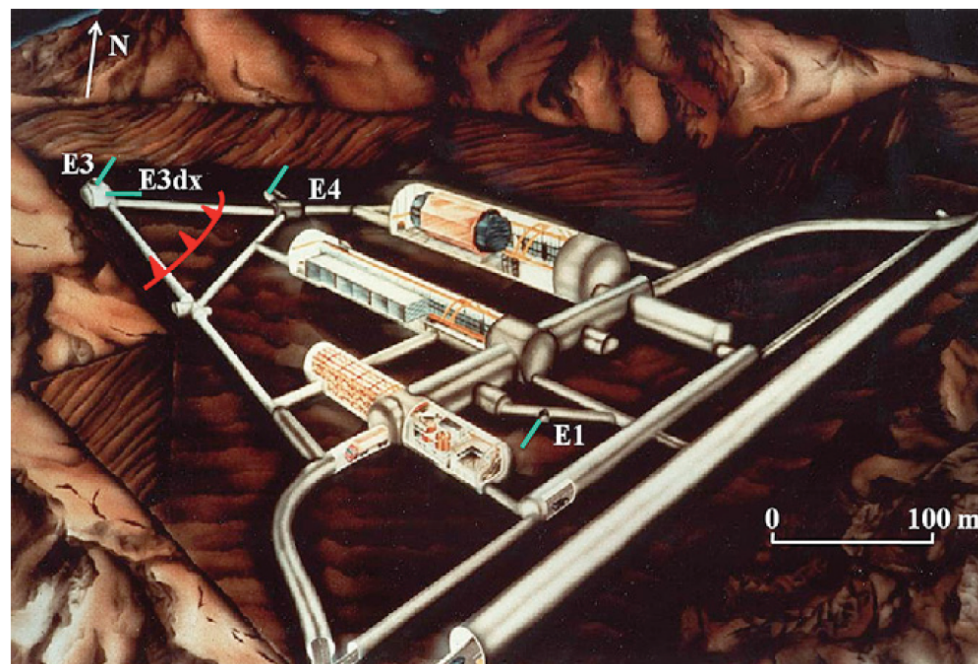
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$$\begin{aligned} \text{MDA or MDC/EFT} &= 0.95/11 \cong 0.08 \text{ Bq kg}^{-1} \text{ or} \\ &\cong 0.7 \text{ TU for l.e. and} \\ &= 0.95/22 = 0.04 \text{ Bq kg}^{-1} \text{ or} \\ &\leq 0.4 \text{ TU for h.e.,} \end{aligned}$$

^{238}U and ^{232}Th activities in LNGS rock

Hall	Activities (ppm)	
	^{238}U	^{232}Th
A	6.80 ± 0.67	2.167 ± 0.074
B	0.42 ± 0.10	0.062 ± 0.020
C	0.66 ± 0.14	0.066 ± 0.025

Wulandari, H. *et al.*, 2004. Neutron flux at the Gran Sasso underground laboratory revisited. *Astropart. Phys.*, doi: 10.1016/j.astropartphys.2004.07.005



	U 10^{-9} g/g	^3H TU	^{14}C pMC	$\delta^{13}\text{C}$ ‰	$\delta^2\text{H}$ ‰	$\delta^{18}\text{O}$ ‰	pH	ORP/mV	EC $\mu\text{S}/\text{cm}$
E1	0.29 ± 0.01	6.6 ± 0.4	59.5 ± 1.0	-9.64	-72.2	-10.93	8.2 ± 0.1	231 ± 22	255.4 ± 3.0
E3	1.79 ± 0.02	8.8 ± 0.5	57.1 ± 1.0	-6.68	-74.6	-11.28	8.2 ± 0.1	232 ± 22	169.3 ± 2.0
E3dx	1.47 ± 0.02	11.2 ± 0.6			-74.4	-11.22	8.3 ± 0.1	228 ± 22	169.1 ± 2.0
E4	0.54 ± 0.01	10.1 ± 0.6	71.7 ± 1.0	-5.74	-72.6	-11.07	8.2 ± 0.1	240 ± 22	159.1 ± 2.0

Plastino, W., *et al.*, 2009. Environmental radioactivity in the ground water at the Gran Sasso National Laboratory (Italy): a possible contribution to the variation of the neutron flux background. *J. Radioanal. Nucl. Chem.*, 282, 809-813.



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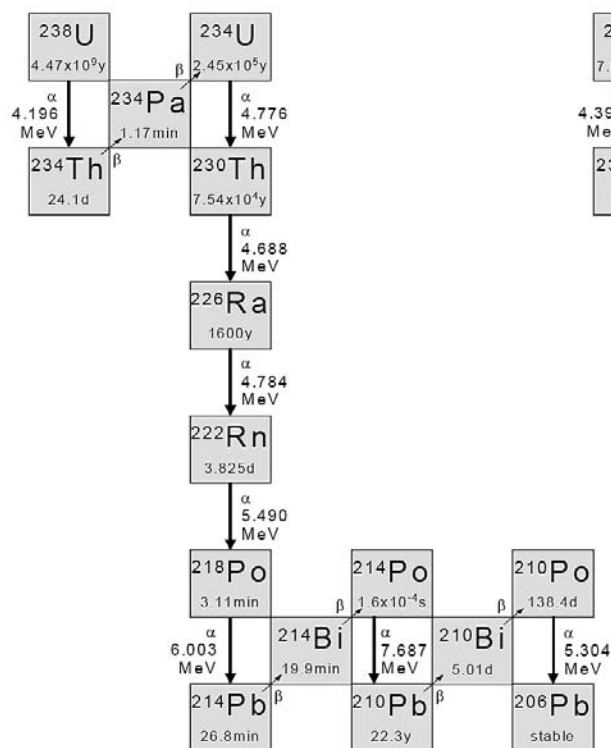
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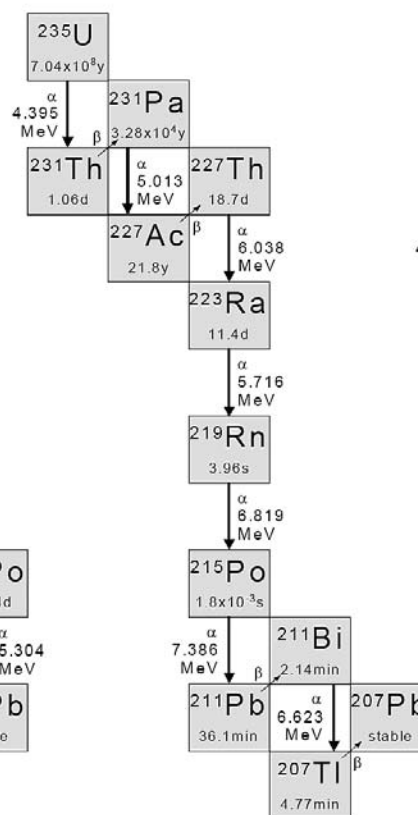
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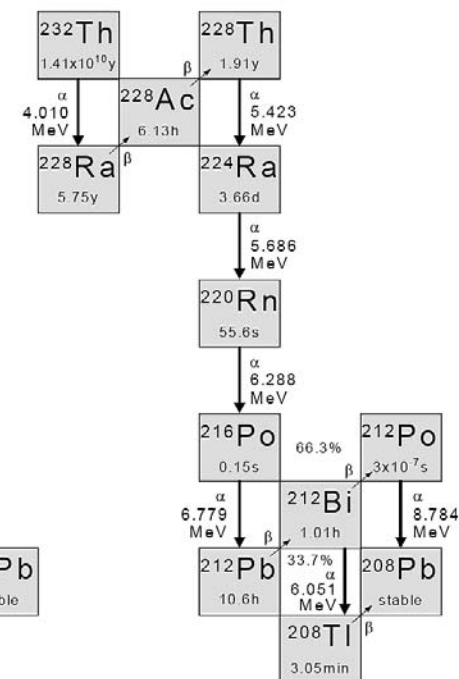
^{238}U -Series



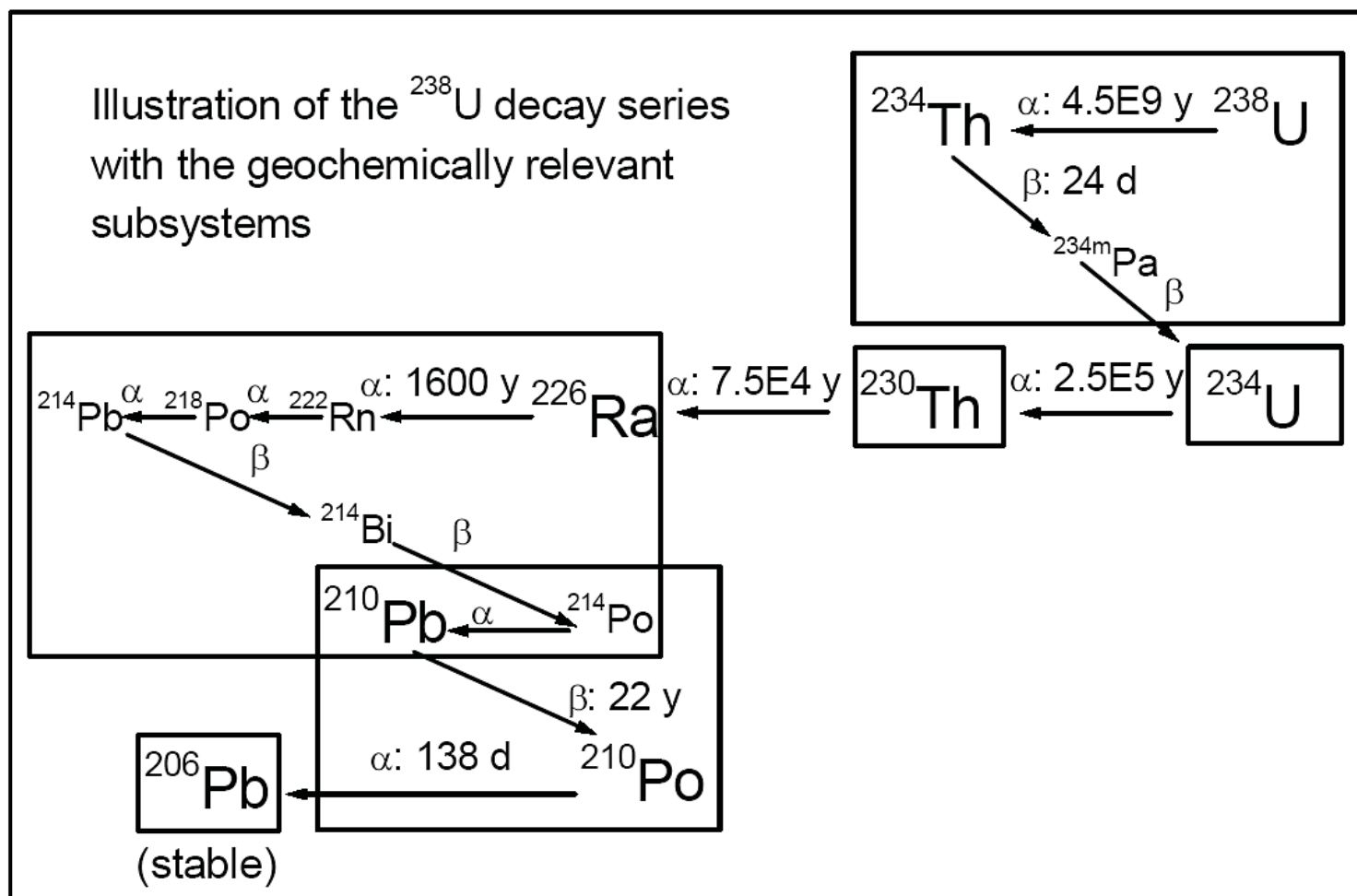
^{235}U -Series



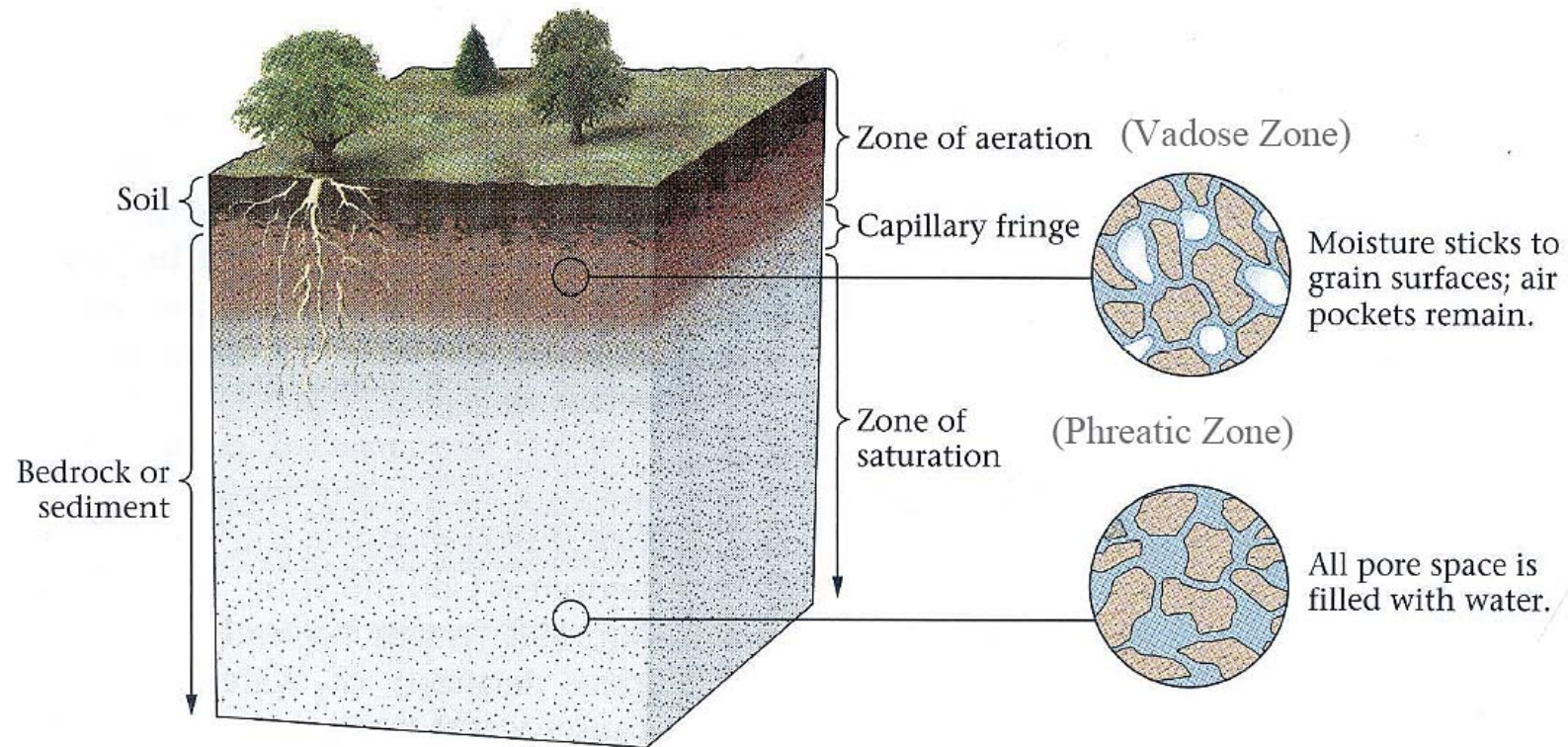
^{232}Th -Series



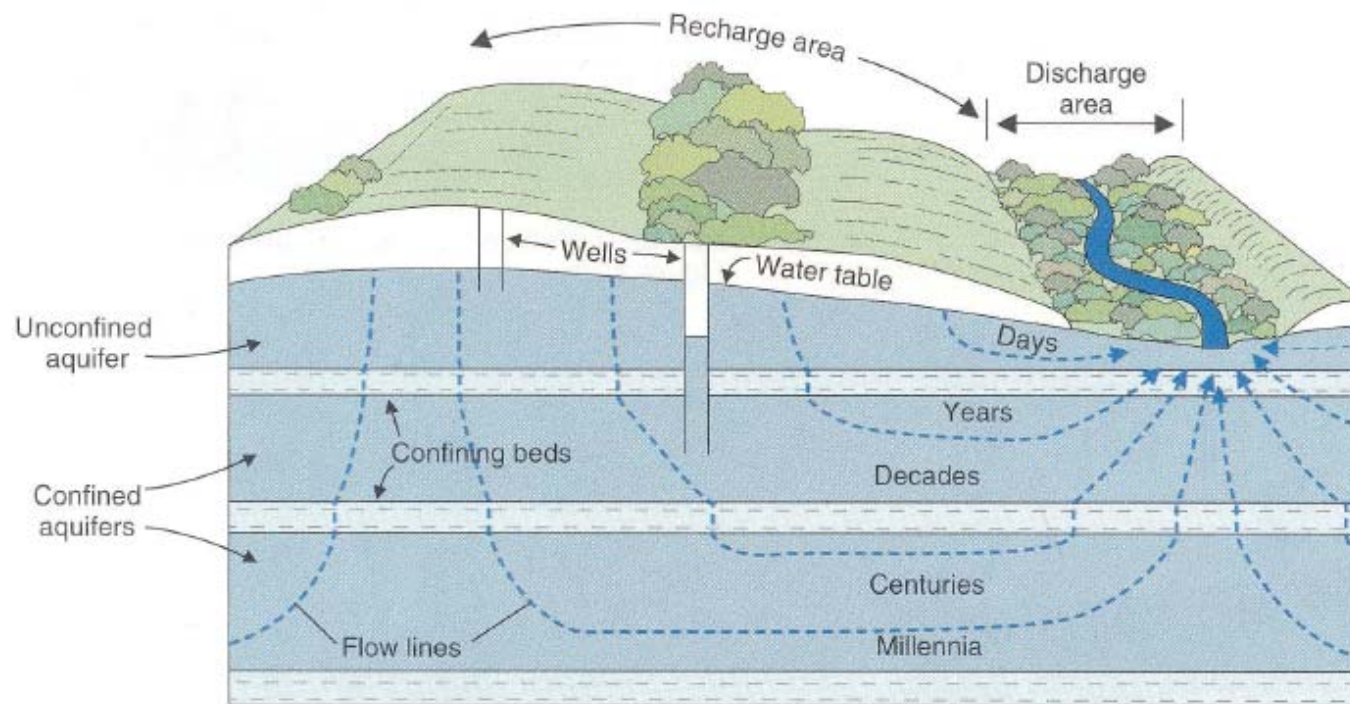
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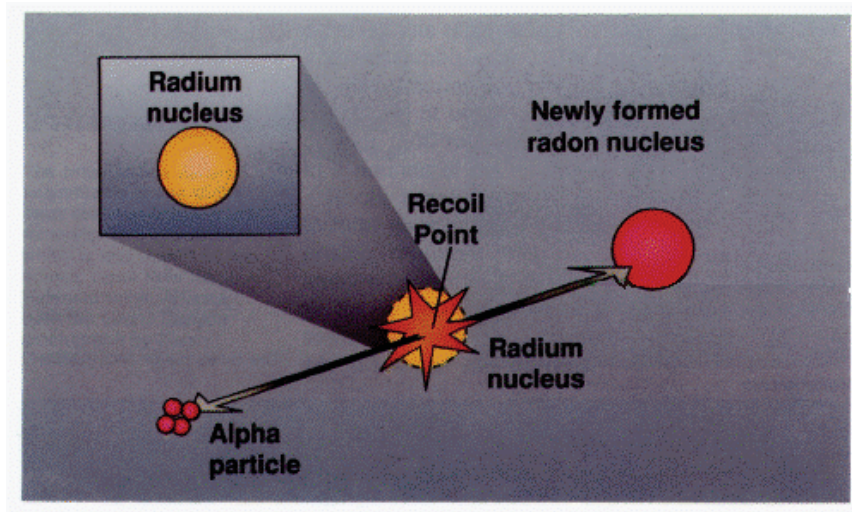
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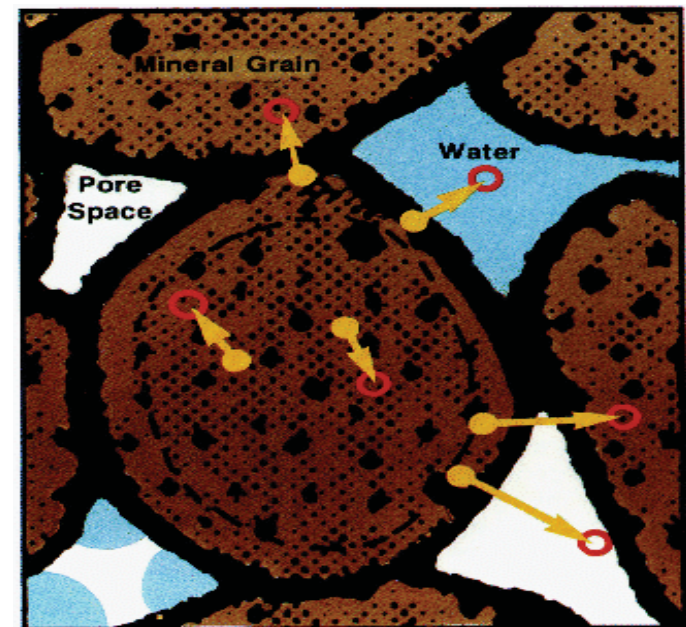


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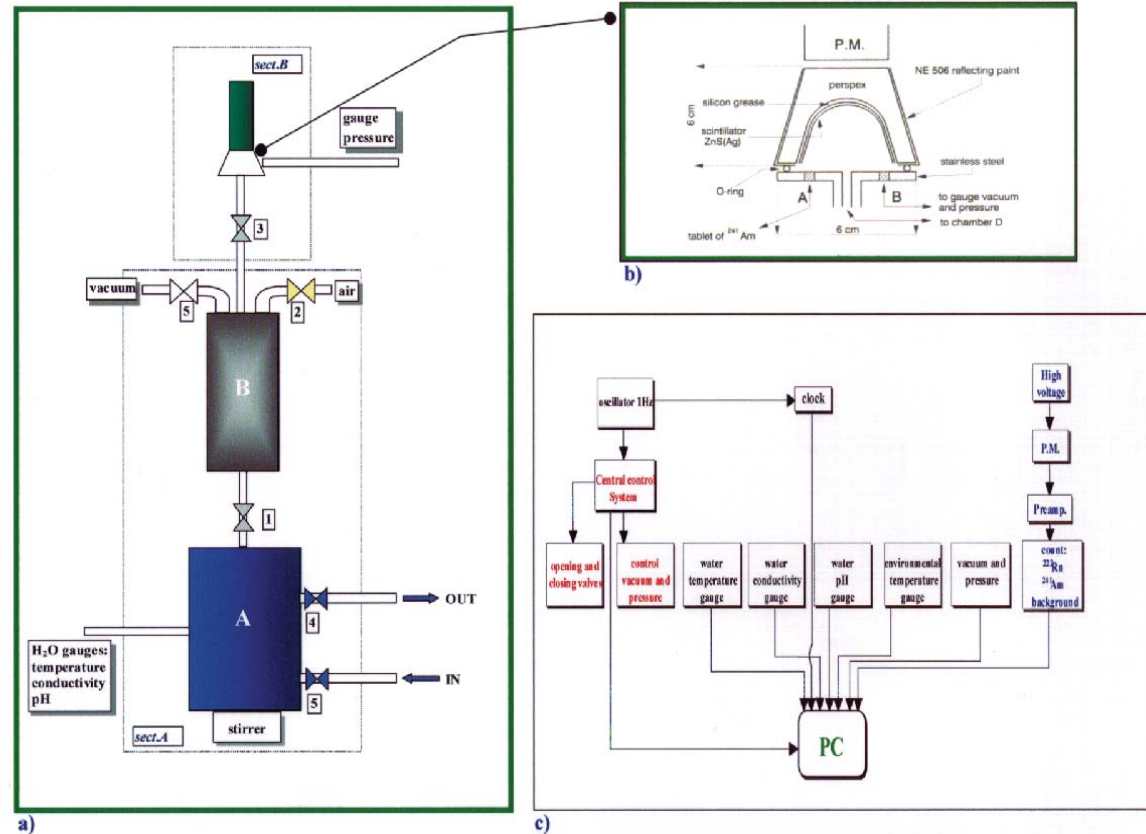


Radium decay involves the release of the excess energy which is shared between the α particle which forms (98.1%), and the new radon atom

The emanating power of rocks is defined as the ratio between the amount of radon escaping from the solid matrix and that produced by radioactive decay



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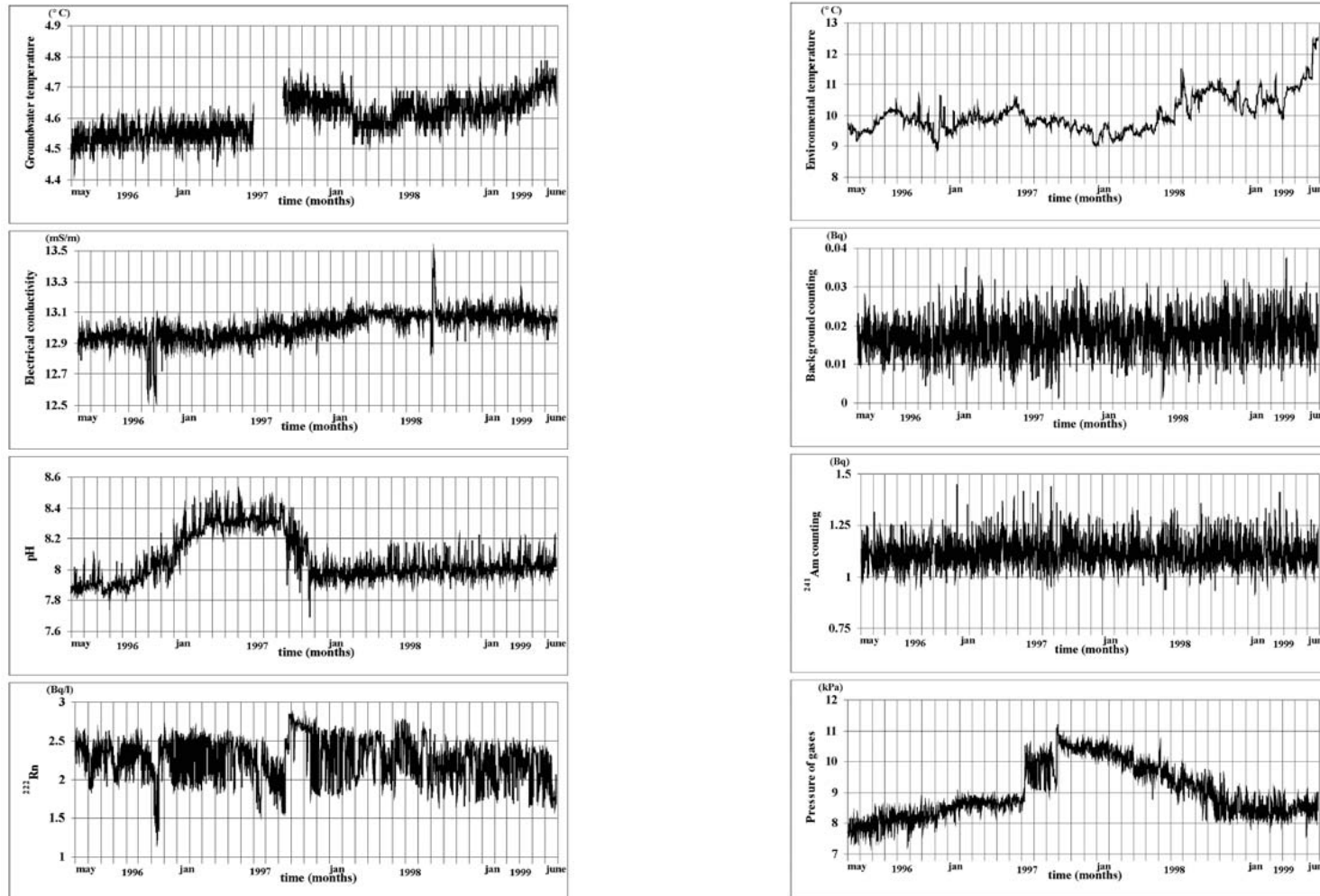


Plastino, W. and Bella, F., 2001. Radon groundwater monitoring at underground laboratories of Gran Sasso (Italy). *Geophys. Res. Lett.*, 28, 2675-2677



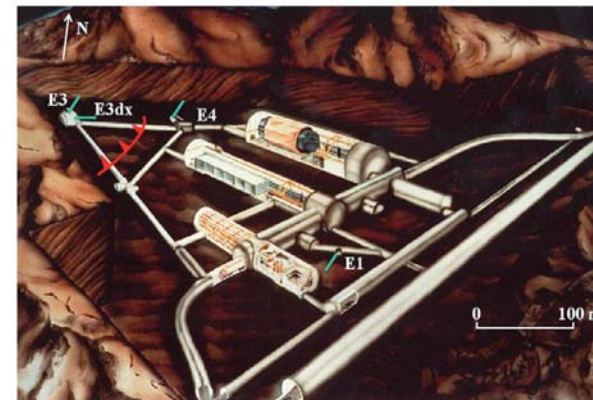
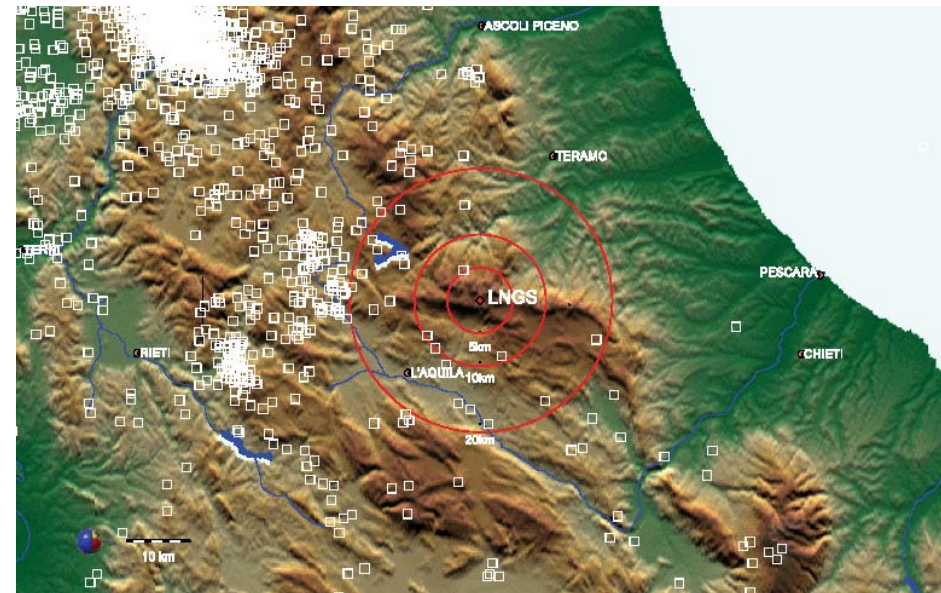
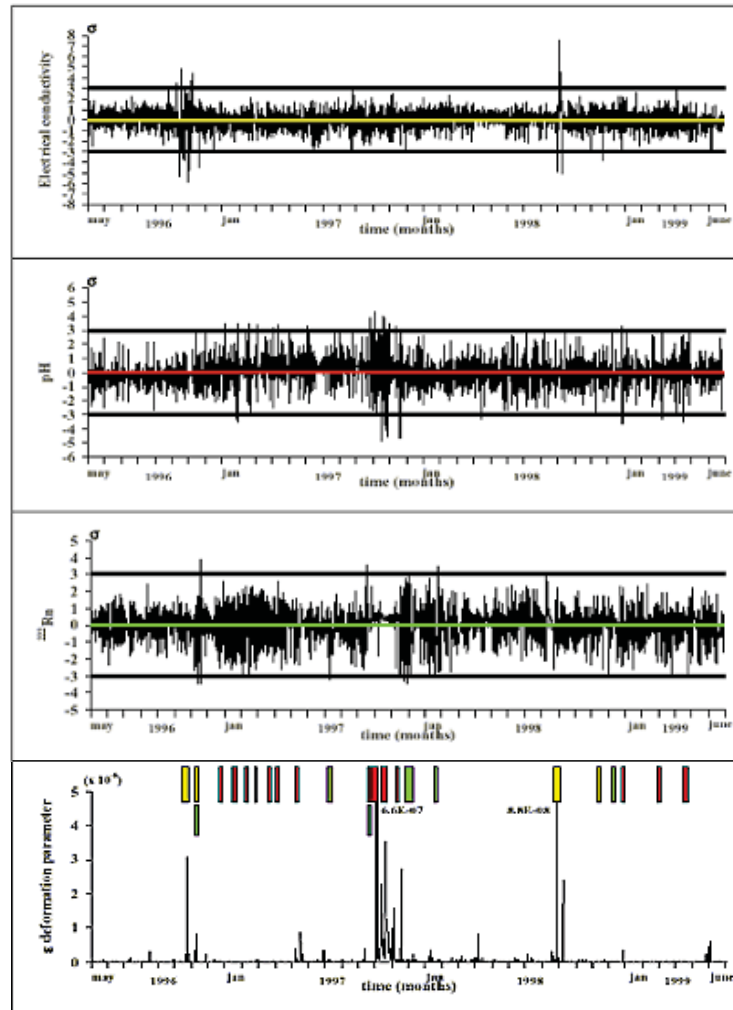
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Plastino, W. and Bella, F., 2001. Radon groundwater monitoring at underground laboratories of Gran Sasso (Italy). *Geophys. Res. Lett.*, 28, 2675-2677.

Plastino, W., 2006. Monitoring of geochemical and geophysical parameters in the Gran Sasso aquifer. *Radionuclides in the Environment*, 11, 225-240.



Caputo, M. and Plastino, W., 2004. Diffusion in porous layers with memory. *Geophys. J. Int.*, 158, 385-396

Plastino, W., 2006. Monitoring of geochemical and geophysical parameters in the Gran Sasso aquifer. *Radionuclides in the Environment*,

Earth science

Radon and rock deformation

Evelyn Roeloffs

What happens when stress is applied to rocks in the Earth's crust so that the crust deforms? This is a question tackled by Trique *et al.* on page 137 of this issue¹. They have used a natural laboratory in the French Alps — the Roselend reservoir — to monitor the geophysical signals that result from the greater or lesser pressure on the underlying crust exerted by the weight of water in the reservoir. This area is not itself prone to earthquakes. But the broader interest of this work is in what it may tell us about the events, induced by crustal deformation, that precede earthquakes.

The ability to predict earthquakes is of course highly desirable. But progress in this difficult and highly contentious science will depend on detecting and interpreting physical changes stemming from the processes

of earthquake generation. Many possible precursors have been reported, but seismologists are sceptical of those that are not clearly linked to crustal deformation. This 'unproven' category includes the well-documented precursory decrease and increase of radon concentration before the 1978 Izu-Oshima earthquake in Japan² (Fig. 1), as well as the controversial assertion that

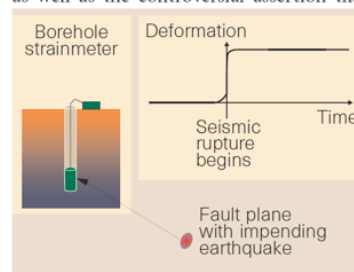


Figure 2 Rock friction, which depends on slip rate and sliding-induced changes on a fault surface, implies that seismic slip should be preceded by accelerating aseismic slip near the hypocentre of an impending earthquake. Sufficient aseismic slip would produce near-surface deformation detectable by a borehole strainmeter. Compared with the strain step recorded at the time of the earthquake, the precursory strain signal would be in the same direction but of much smaller amplitude. A magnitude-5 earthquake, 10 km deep, produces maximum near-surface strain of about 10^{-7} at a site 5 km from its fault plane; strain increases 30-fold for each unit increase of magnitude, but falls off as the third power of distance from the source. Estimates of pre-seismic slip duration and amplitude range widely because frictional parameters of natural faults are poorly known.

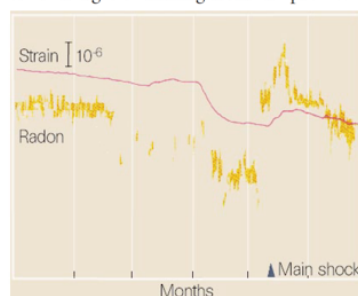


Figure 1 The radon and strain data for the magnitude-7 Izu-Oshima earthquake^{2,9} of 14 January 1978 show changes preceding the earthquake. But they do not match the model shown in Fig. 2; in particular, neither change is monotonic, and in both cases the pre-earthquake change exceeds that produced by the earthquake itself.

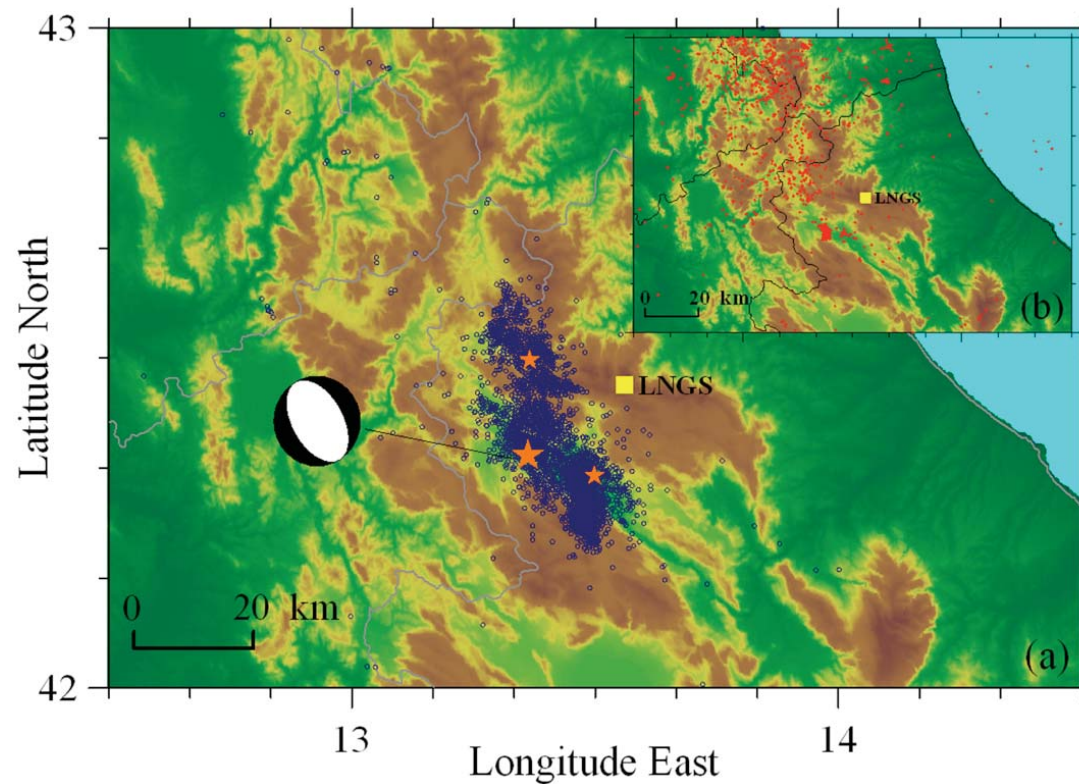
deformation of crustal rocks.

Seismologists expect earthquake precursors to take the form of transient crustal-strain signals from 'aseismic' fault slip near the earthquake's nucleation point (that is, fault slip that is too slow to radiate seismic waves) (Fig. 2). Numerical simulations show, however, that such signals would be exceedingly small⁴. Even the best existing instruments — borehole strainmeters with resolution exceeding a part per billion — would need to be within a few kilometres of the impending earthquake's epicentre to detect this aseismic strain. Although strain changes preceding two California earthquakes have been identified^{5,6}, they don't resemble the expected signals.

Proponents of earthquake prediction maintain that changes in radon emission, or in electrical or magnetic fields, represent a natural amplification of pre-earthquake deformation under special geological conditions. For example, the conductance by rock fractures of water or gas is proportional to the third power of the fracture's aperture⁷. Fluid flow past ions adsorbed on rock surfaces produces an electric field, termed a 'streaming potential', that varies with pressure gradient and permeability⁸. Fluid, gas or electromagnetic measurements might thus detect deformation indirectly, albeit at localized sites and with amplitudes related nonlinearly to strain.

Silver and Wakita⁹ list many potential examples of such pre-earthquake 'strain indicators'. Unfortunately, these indicators are irreproducible: they can be detected only in certain locations, but in any one location earthquakes recur infrequently. What is needed is evidence that transient strain leads consistently, if not linearly or uniformly, to observable phenomena. The radon, electrical and ground-tilt measurements from Roselend lake constitute this kind of reproducible evidence.

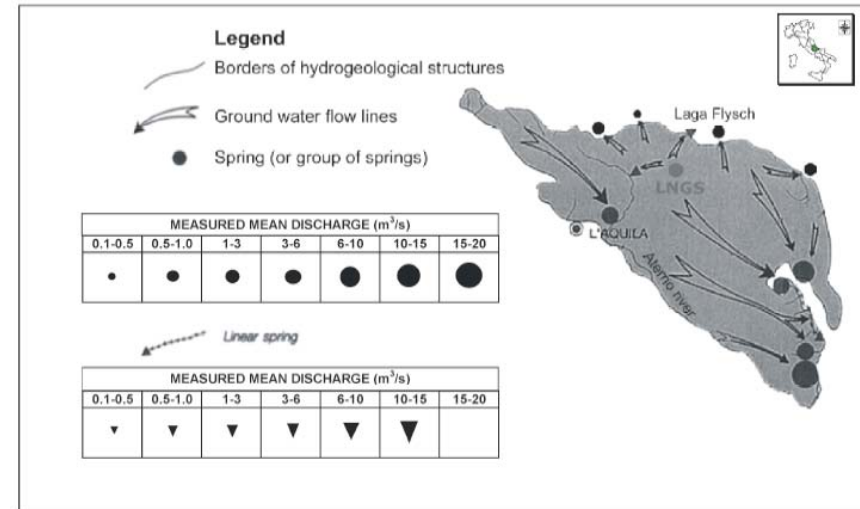
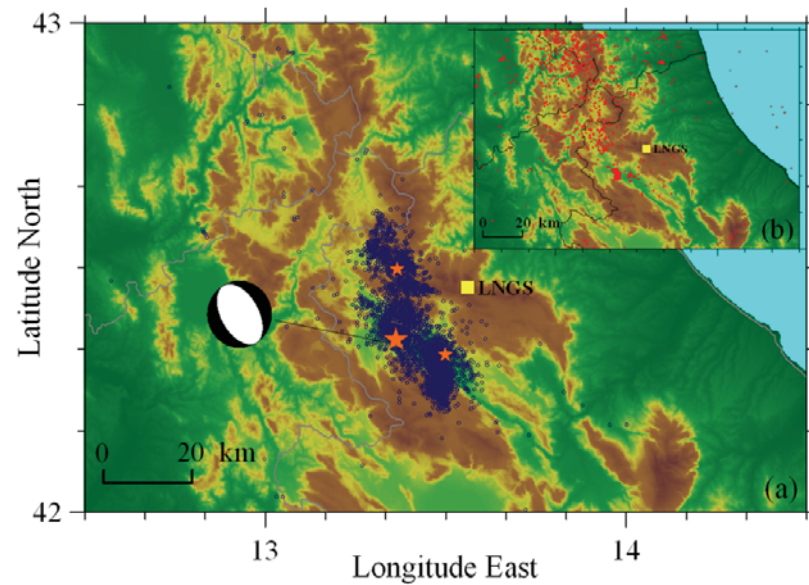
The shallow crust's reaction to large changes in lake level may also illuminate the



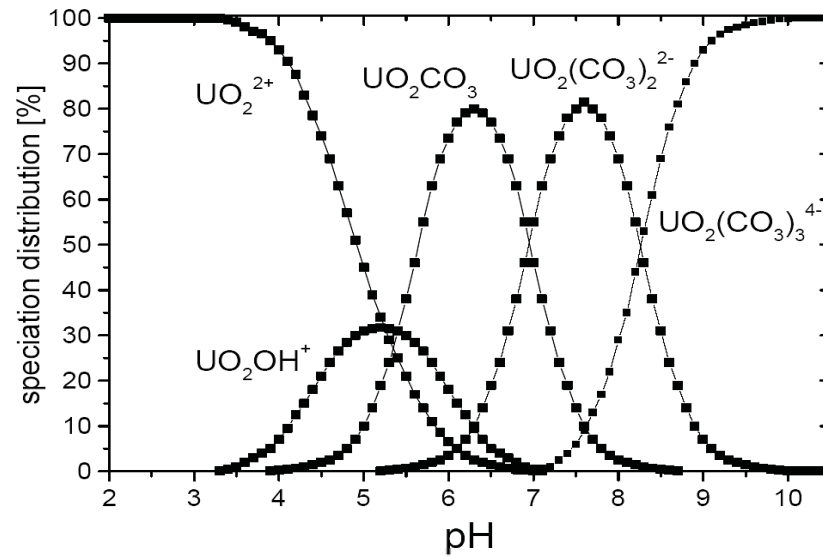
Plastino, W. et al., 2010. Uranium groundwater anomalies and L'Aquila earthquake, 6th April 2009 (Italy). *J. Environ. Radioact.*, 101, 45-50.



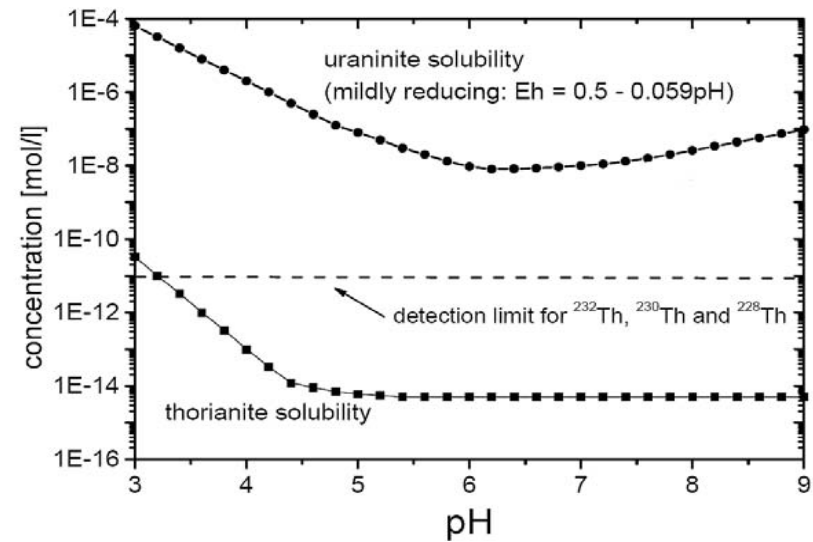
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Boni *et al.*, Mem. Soc. Geol. It., 1986



Langmuir, Geoch. Cosmoch. Acta, 1978

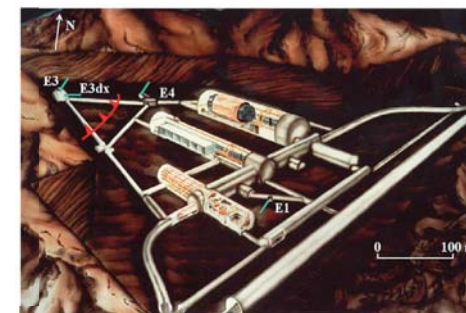
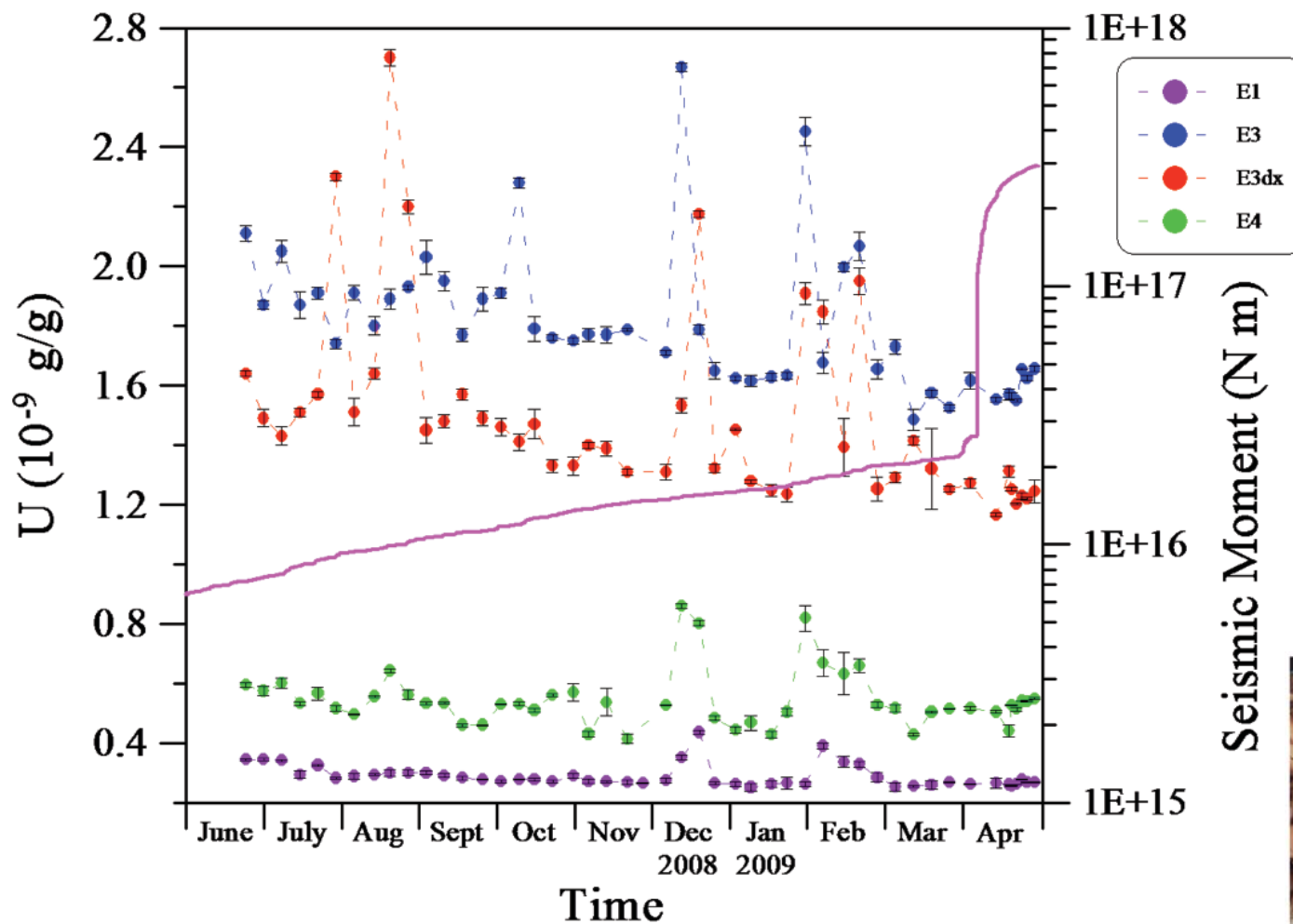


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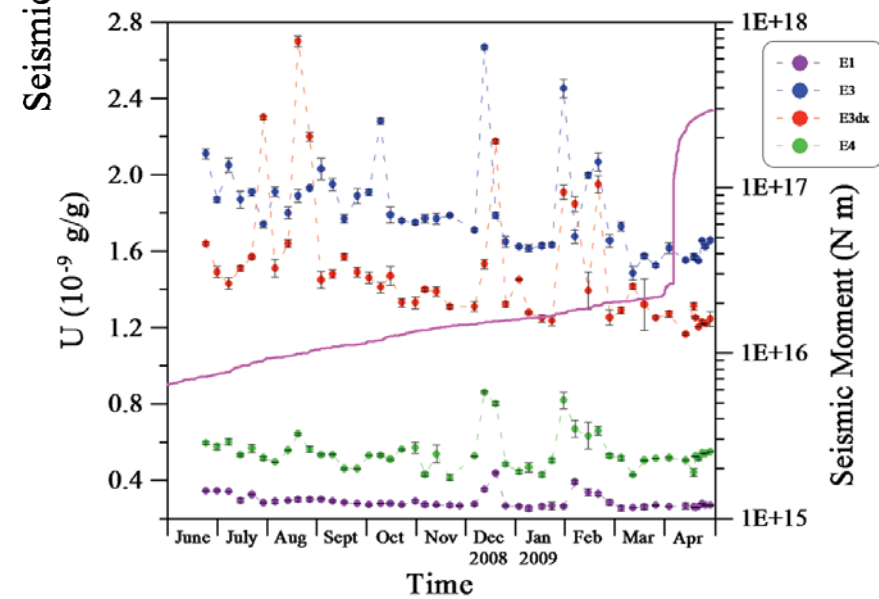
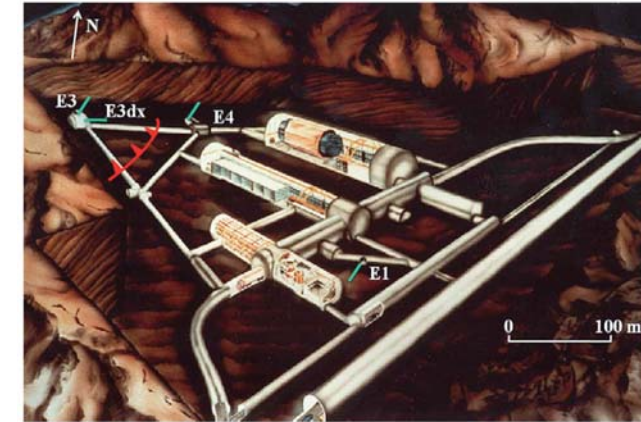
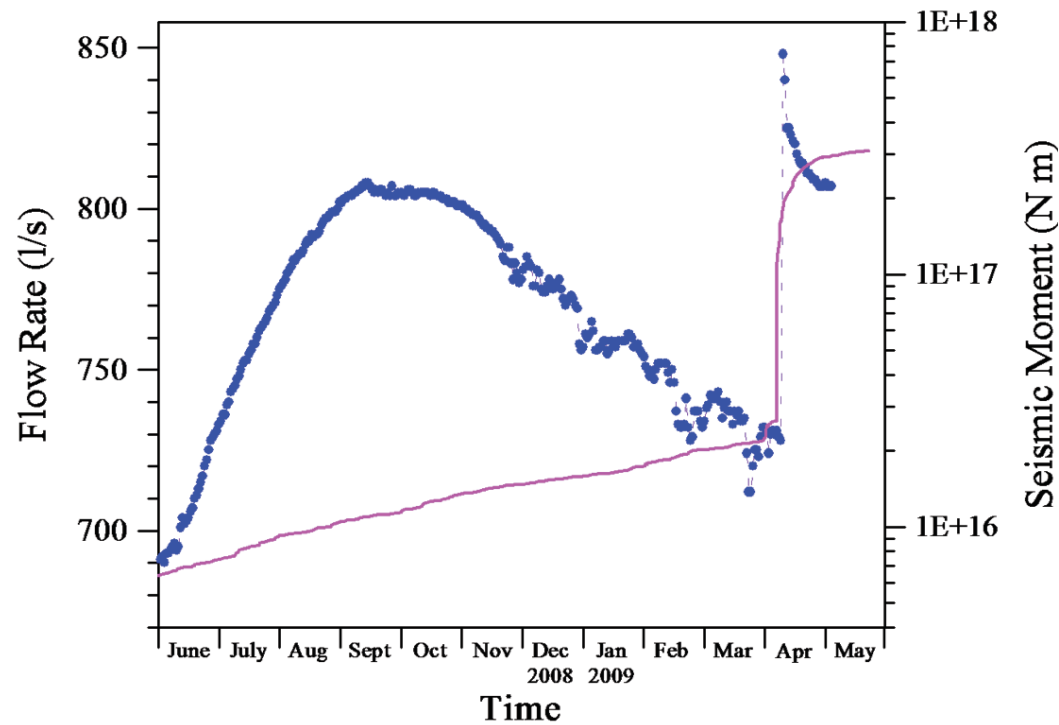


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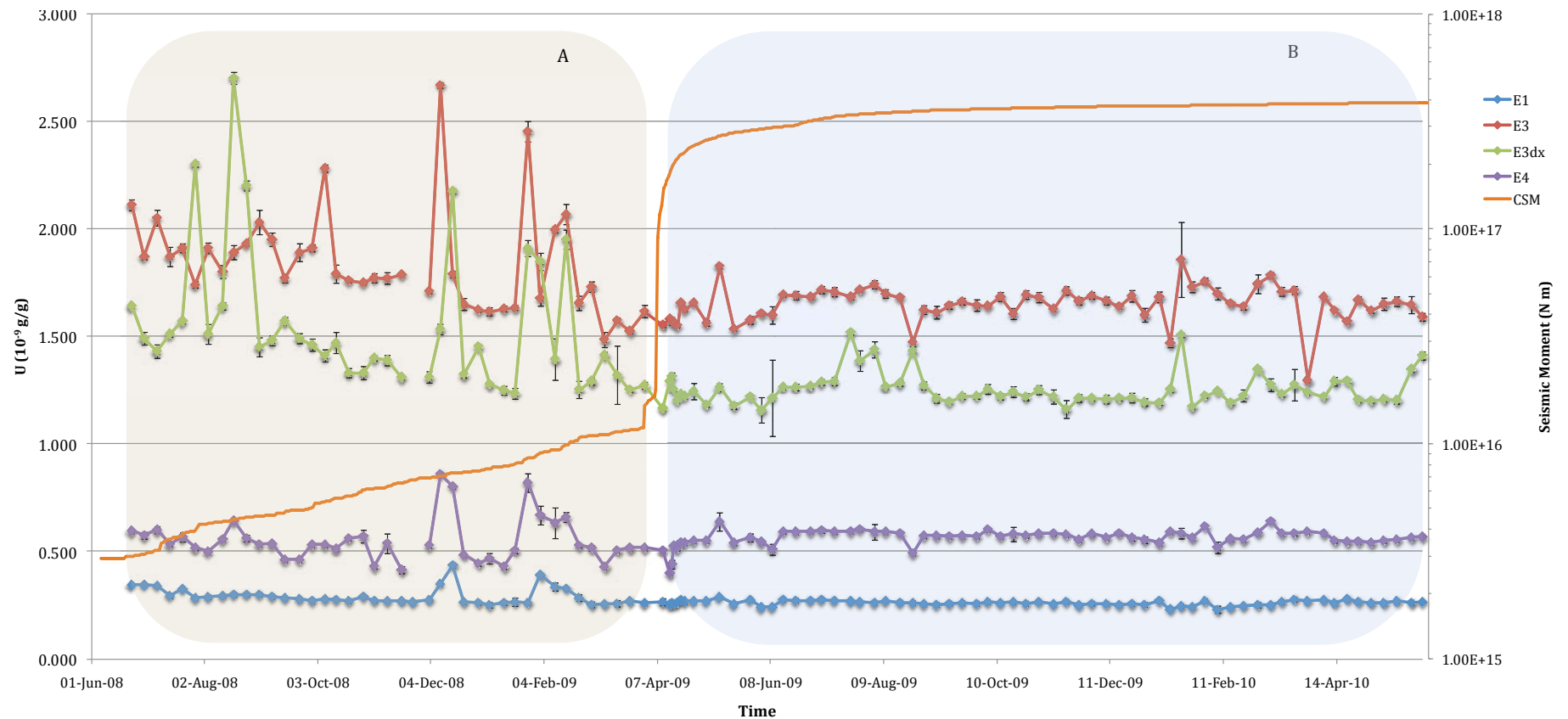


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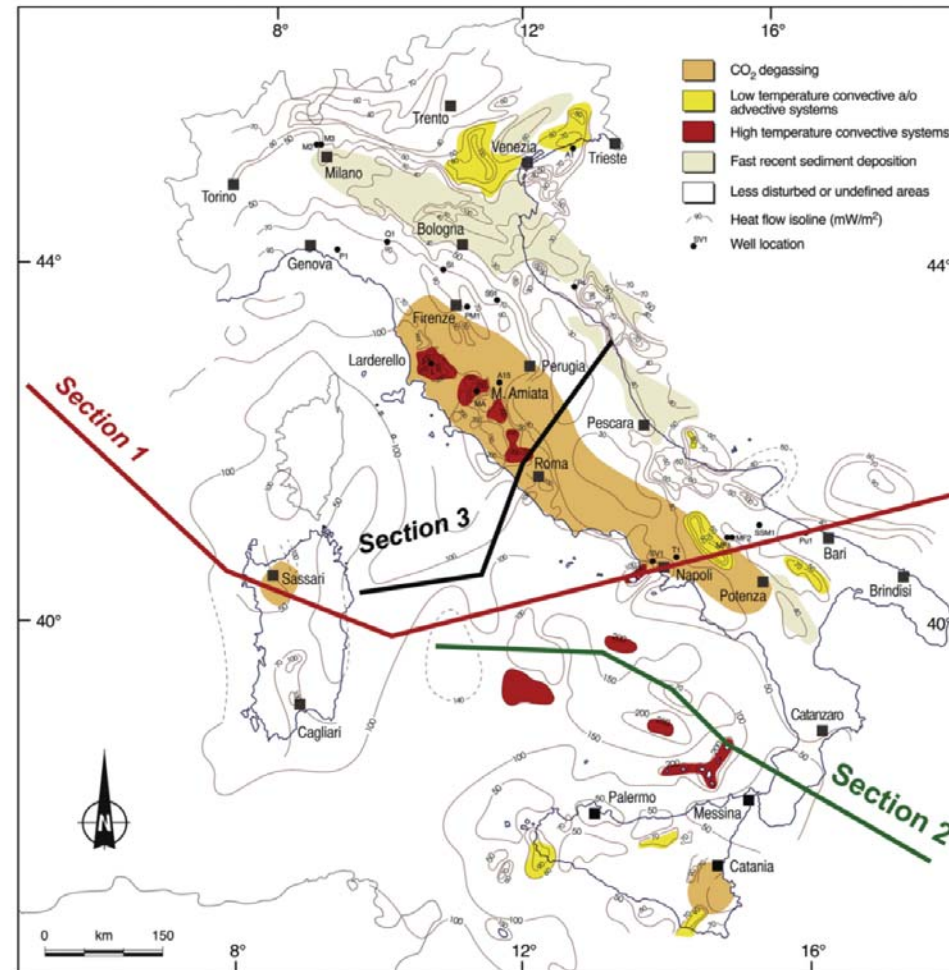


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Plastino, W. *et al.*, 2011. Uranium groundwater anomalies and active normal faulting. *J. Radioanal. Nucl. Chem.*, 288, 101-107.



Frezzotti, M.L., et al., Carbonate metasomatism and CO₂ lithosphere–asthenosphere degassing beneath the Western Mediterranean: An integrated model arising from petrological and geophysical data, *Chem. Geo.* (2009), doi:10.1016/j.chemgeo.2009.02.015.



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Table 1 Summary of statistical analysis (Relative Standard Deviation, Mean, Covariance and Correlation with U) for each site and simultaneous readings of U, Na, Mg, K, Ca, EC, ORP, and pH, during the periods A (from 23rd June 2008 to 31st March 2009) and B (from 10th April 2009 to 31st May 2010). Each series was normalized to the corresponding average

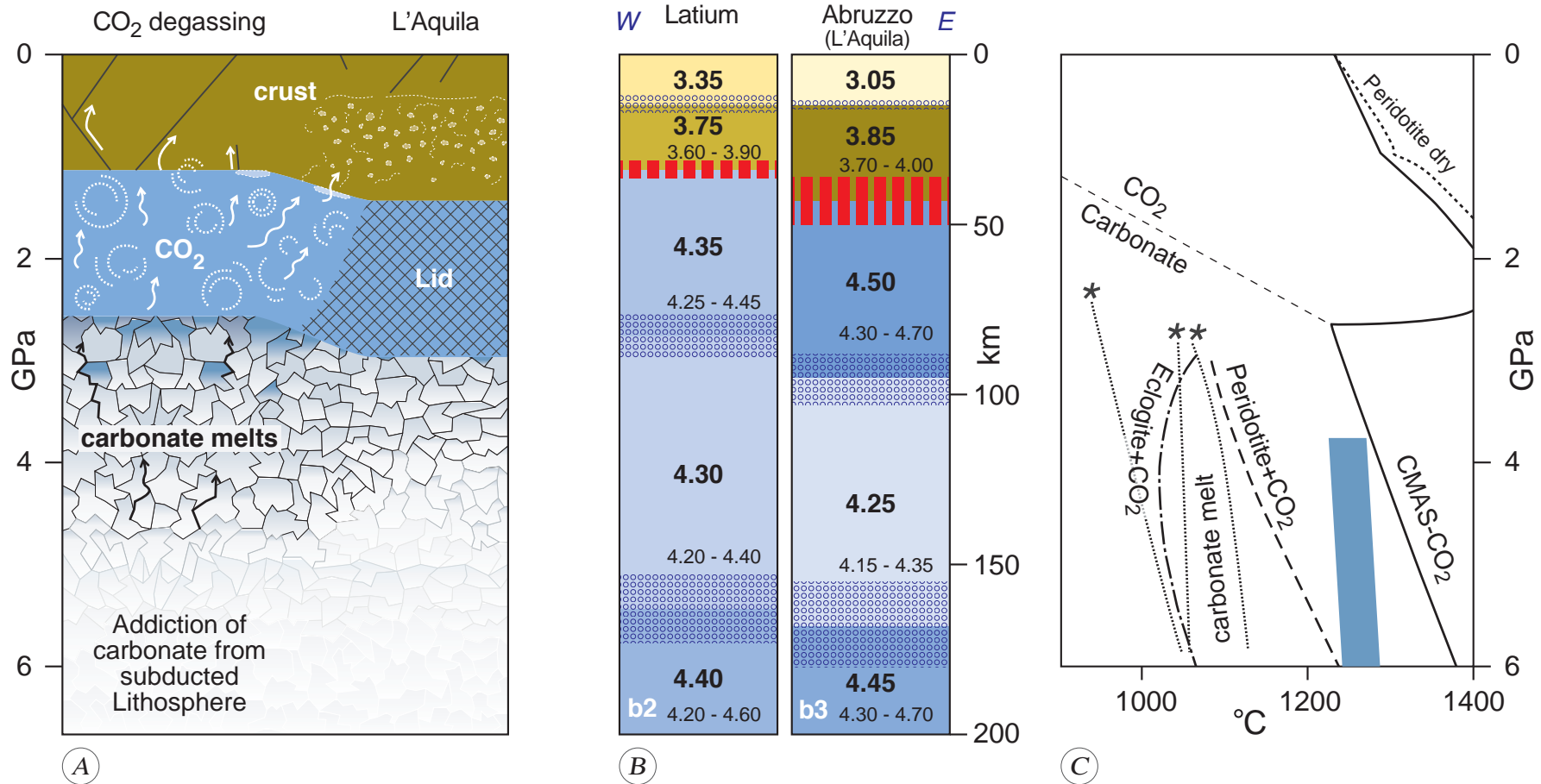
	U	Na	Mg	K	Ca	EC	ORP	pH
A								
E1								
RSD	0.145	0.148	0.134	0.272	0.130	0.026	0.063	0.024
Mean	1.073	1.079	1.015	1.081	1.030	0.967	0.987	1.014
Cov (U, X)	0.020	0.019	0.017	0.027	0.016	0.000	-0.002	-0.001
Corr (U, X)	1.000	0.935	0.877	0.714	0.886	-0.095	-0.236	-0.174
E3								
RSD	0.139	0.158	0.137	0.419	0.132	0.024	0.047	0.025
Mean	1.072	1.075	1.022	1.105	1.040	0.973	1.038	1.002
Cov (U, X)	0.019	0.019	0.016	0.029	0.017	0.000	0.000	0.000
Corr (U, X)	1.000	0.874	0.851	0.517	0.937	-0.062	-0.033	0.023
E3dx								
RSD	0.241	0.240	0.221	0.366	0.219	0.022	0.046	0.017
Mean	1.134	1.099	1.066	1.143	1.092	0.987	1.032	1.003
Cov (U, X)	0.057	0.050	0.047	0.065	0.048	0.000	0.000	-0.001
Corr (U, X)	1.000	0.884	0.906	0.752	0.931	-0.019	0.019	-0.130
E4								
RSD	0.183	0.171	0.150	0.403	0.165	0.030	0.053	0.021
Mean	0.967	1.069	1.033	1.175	1.051	0.979	1.076	0.999
Cov (U, X)	0.033	0.024	0.023	0.046	0.026	0.000	0.002	0.000
Corr (U, X)	1.000	0.775	0.872	0.645	0.896	0.080	0.267	-0.127
B								
E1								
RSD	0.041	0.036	0.035	0.088	0.036	0.026	0.054	0.008
Mean	0.956	0.952	0.991	0.952	0.982	1.020	1.008	0.991
Cov (U, X)	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.000
Corr (U, X)	1.000	0.400	0.181	0.141	0.309	0.002	0.173	-0.102
E3								
RSD	0.049	0.040	0.034	0.108	0.038	0.021	0.057	0.012
Mean	0.957	0.956	0.986	0.928	0.977	1.016	0.977	0.999
Cov (U, X)	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Corr (U, X)	1.000	0.115	0.074	-0.010	-0.081	0.138	-0.148	-0.033
E3dx								
RSD	0.056	0.132	0.043	0.157	0.040	0.026	0.053	0.011
Mean	0.920	0.940	0.961	0.919	0.946	1.008	0.982	0.998
Cov (U, X)	0.003	0.002	0.001	0.002	0.001	0.000	0.001	0.000
Corr (U, X)	1.000	0.309	0.496	0.193	0.554	0.226	0.302	-0.460
E4								
RSD	0.069	0.045	0.041	0.103	0.040	0.023	0.062	0.021
Mean	1.009	0.959	0.980	0.904	0.970	1.013	0.955	1.001
Cov (U, X)	0.005	0.002	0.002	0.003	0.001	0.001	0.001	0.000
Corr (U, X)	1.000	0.624	0.554	0.419	0.470	0.356	0.271	-0.158

Plastino, W. *et al.*, 2011. Uranium groundwater anomalies and active normal faulting. *J. Radioanal. Nucl. Chem.*, 288, 101-107.



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Conclusions

More attention should be devoted to the pre-earthquake and volcanic eruption studies of geodynamic processes, especially on characteristics of fluids filling the fractures before the main shock and eruption. Uranium in groundwater has been tested as a potential indicator of pre-earthquake processes as it may be associated with geodynamics of preparation phases of earthquakes.

Another possible physical process during the pre- and post-phases of the earthquake could be investigated: the first stage seems to be characterized by U variations in groundwater that can modulate the radon concentration, the second one (after the main shock) do not show any U anomalies, justifying the different radon patterns before and after the main shock.



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