Seismic sequence Capo di Giano 14/05/2023 - – now

G. Festa, F. Carotenuto, S. Colombelli, G. De Landro, L. Elia, A.G. Iaccarino, V. Longobardi, T. Muzellec, S. Nazeri, M. Palo, M. Picozzi, R. Rea, G. Russo, A. Scala, F. Scotto di Uccio, C. Strumia, S. Tarantino, M. Adil, A. Zollo



RISSC-Lab: Laboratorio di RIcerca in Sismologia Sperimentale e Computazionale



Summary



We are experiencing a seismic sequence (more than 240 events detected), occurring in the Muro Lucano – Capo di Giano area (PZ), at a depth between 7 and 9 km, at the Eastern boundary of the INFO, Irpinia Near Fault Observatory. The area was struck in the past by seismic events of magnitude > 6.0.





CATALOG

Catalog enhancement

We performed an advanced detection analysis based on Scotto di Uccio et al. (2023) integrating machine learning (**EQTransformer**, Mousavi et al. 2020) and template matching (**EQCorrscan**, Chamberlain et al. 2018) techniques. The resulting catalog (**14-23/05**) consists up to now of **246 earthquakes**, most of them only visible at VDS3 station.



Z-map analysis for G-R computation



Time-magnitude distribution of the events. In red events featuring MI > 1.5

The G-R law feature **consistent b-value** (0.89 ± 0.10) with the ones estimated for sequences in the area (Scotto di Uccio et al., 2023). Local magnitude have been estimated assuming colocation.

3D Absolute locations



We performed absolute locations of 33 events with NLLoc (Lomax, 2009) and the 3D P- and S-wave models optimized for the area (De Landro et al. 2022). The yellow star represents the mainshock. The colours correspond to the time occurrence of events after the mainshock. The gray dashed lines in plane view represent the projection of SW-NE and NW-SE sections. The black lines represent the fault traces as mapped by Bello et al. (2022). The 20 best located events (errors < 1 km), in the figure below, show a clustered distribution within less than 2 km from the mainshock.



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3D Double-Difference locations



We performed double difference locations of events of the sequence with HypoDD, using catalog and crosscorrelation differential times. The gray dashed line in plane view (a) represent the projection of SW-NE section (b). The white star represents the mainshock location. The color is related to the occurrence time. The location errors are whitin 100 meters and the average rms is 0.06 s. The sequence distribution in plane and section is coherent with the retrieved focal mechanism (see slide 11).





Source Parameters – SPAR



We inverted displacement amplitude spectra at stations of ISNet using a generalized Brune source model, through the software **SPAR** (Supino et al., 2019). For the main event we estimated an average moment magnitude of 2.78 \pm 0.02, a corner frequency of 3.8 \pm 0.2 Hz and a stress drop of 1.0 \pm 0.1 MPa (Left panel). For the inversion we set $v_s = 3030$ m/s and $Q_s = 230$. The histogram represents the distribution of the moment magnitude for 40 events in the sequence (Right panel).





Source Parameters – SPAR



We found that corner frequencies show values ranging from 1Hz to 10 Hz and correspond to larger stress drops for larger magnitude. Saturation of corner frequency is observed for low moment magnitudes (moments < 5 10¹¹ Nm). Stress drops (b) for the sequence have been found to vary between 10KPa and 1 Mpa, with few outliers.





Time-domain, single-station estimates of source parameters for the mainshock



TD S-wave TDP TDS THDS TDS 0.8 0.9 0.8 0.7 · 0.7 0.6 <u>3</u> 0.6 0.5 0.5 0.4 0.4 0.3 ન 0.3 0.2 8 0.2 S 0.1 0.1 0 0 -0.1 0 15 -0.1 0 -20 10. -20 Distance [km] Distance [km]

- (half)(total) Pulse widths are corrected for the attenuation (Qp=160; Qs=220) using the Kjartansson(1979) linear relation (k coefficients calibrated in J.Zheng et al, 2023 in preparation)
- Average source durations:
 - P-wave → ToHD=0.13±0.06 sec; ToD=0.26±0.16 sec
 - S-wave→ ToHD=0.15±0.08 sec; ToD=0.27±0.17 sec

Source parameters – P wave

Parameter	Formula	Value
Seismic moment	$\langle M_0^c angle = rac{2\pi ho v_c^2}{F_S R_{\theta \phi}^c} \langle P d_c^0 \cdot R angle \langle To Dc angle$	$2.4 \times 10^{13} Nm$
Moment magnitude	$M_W = (\log(M_0^{P.S}) - 9.1)/1.5$	2.8
Rupture radius	$\bar{a} = ToHD_e v_R (1 - \frac{2v_R}{\pi v_e})^{-1}$	440 m
Static Stress-Drop	$\Delta\sigma=\frac{7}{16}\frac{\langle M_o\rangle}{\bar{a}^3}$	0.1 MPa
Equivalent fc (S&Hmodel)	$f_c = 0.42 \frac{v_p}{a}$	4.3 Hz

Source parameters – S wave

Parameter	Formula	Value
Seismic moment	$\langle M^c_0 angle = rac{2\pi ho u^2_c}{F_S R^c_{ heta arphi}} \langle P d^0_c \cdot R angle \langle T o D c angle$	$3.1 \times 10^{12} Nm$
Moment magnitude	$M_W = (\log(M_0^{P,S}) - 9.1)/1.5$	2.3
Rupture radius	$\bar{a} = ToHD_e v_R (1 - \frac{2v_R}{\pi v_e})^{-1}$	383 m
Static Stress-Drop	$\Delta\sigma=\frac{7}{16}\frac{\langle M_o\rangle}{\bar{a}^3}$	0.15 MPa*
Equivalent fc (S&Hmodel)	$f_c = 0.29 \frac{v_S}{a}$	1.9 Hz





Time-domain, average-based estimate of source parameters of the mainshock, EASOt-AP



LPDT/LSDT: Logarithm of P- and S-wave Displacement signal as a function of Time

 input Parameters								
Vp (km/s)	Vp/Vs	Qp/Qs						
5.5	1.8	167/224						

Table 1: Both P- and S-wave observations are used to estimate Vr, average a, and expected corner frequency.

Wave	Tc (s)	Vp (km/s)	Vs (km/s)	a (m)	Vr/Vs	Fc (Hz)
Р	0.13		2.1	224.0	0.0	5.8
S	0.1	5.5	3.1	324.0	0.6	2.5

Table 2: Source Parameters estimation from Individual waves

Wave	Vr/Vs	Vp (km/s)	M0 (Nm)	Mw	a (m)	Δσ (MPa)
Р	0.6	5.5	5.5 8.7e12		302.5	0.1
S	S 0.6		7.3e12	2.5	296.6	0.1

Assuming a triangular moment-rate function, uniform speed, and circular rupture model, source parameters (rupture velocity, seismic moment, fault size and stress drop) are determined implementing a parametric approach based on the time evolution of the P-wave and S-wave amplitudes. The proxy is a logarithm of the P- and Swave displacement vs time curves (LPDT/LSDT). The constant-Q, anelastic attenuation effect is accounted for.





FOCAL MECHANISM

MAP model

Focal Mechanism – Main event



Inversion was performed for the main events by fitting the observed P (c) and S/P (d) amplitudes and the P polarities (b). The best solution shows a strike-slip source mechanism with a normal component.





1.5

0.5

FOCAL MECHANISM

Composite Focal Mechanism

The focal mechanism has been computed for clustered events, as resulting from double difference location, takeoff angles from ray tracing in the 3D model (De Landro et al., 2022), and manually read polarities. We found a focal mechanism consistent with the results obtained for the main event.



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FOCAL MECHANISM

Composite Focal Mechanism

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The measured S-polarization of the mainshock event (ML=2.7, Mw 2.8) are also generally consistent with theoretical horizontal S-vector direction in particular at stations close to the SWdipping plane. A larger discrepancy between observed and theoretical S-polarization is instead observed at station VDS3 that needs further UP DWN + + COMPRESSI







Ground motion (PGV)



- Average epicentral distance ~26 km
 - > Min distances IV.MRLC 6.1 km IX.VDS3 8.3 km
 - > Max distance IX.VGG3 $-59.1 \ km$
- PGV observed on velocimeters (where available) and integrated from accelerometers
- PGV range
 - → $PGV_{min} = 3 \cdot 10^{-5} \, cm/s$ (IX.NSC3)

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 $PGV_{max} = 0.24 \ cm/s \ (IV.MRLC) - 0.14 \ cm/s \ (IX.VDS3)$



Ground motion (PGA)



- PGA range
 - ▶ $PGA_{min} = 1.0 \cdot 10^{-3}\% g$ (IX.VGG3)
 - $PGA_{max} = 0.48\% g$ (IV.MRLC) 0.36% g (IX.SFL3)







Ground motion (IMM)



SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme	
DAMAGE	None	None	None	one Very light Light Moderate Moderate/heav		Moderate/heavy	Heavy	Very heavy		
PGA(%g)	<0.0556	0.212	0.808	1.97	4.82	11.8	28.7	70.1	>171	
PGV(cm/s)	<0.0178	0.0775	0.337	0.898	2.39	6.37	17	45.2	>120	
INTENSITY	1	11-111	IV	V	VI	VII	VIII	DX.	X4+	
Scale based on Faenza and Michelini (2010, 2011) Version 1: Processed 2023-02-08T14:05:04Z										

 \triangle Seismic Instrument \circ Reported Intensity

★ Epicenter



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- Average epicentral distance $\sim 26 \ km$
 - > Min distances IV.MRLC 6.1 km; IX.VDS3 8.3 km
 - > Max distance VGG3 $-59.1 \ km$
- IMM range

$$IMM_{max} = IV (IV.MRLC) III (IX.VDS3 - IX.SFL3)$$

Ground motion (ShakeMaps)



cale based	on Faen	za and	Michelin	i (2010 20	11)	Versi	on 1 · Processed 2	023-05-1	9713-57-59
INTENSITY	1	11-111	IV	×	VI	VII	VIII	DX.	X4+
PGV(cm/s)	<0.0178	0.0775	0.337	0.898	2.39	6.37	17	45.2	>120
PGA(%g)	<0.0556	0.212	0.808	1.97	4.82	4.82 11.8 28.7		70.1	>171
DAMAGE	None	None	None	Very light	Light	Moderate	Moderate/heavy	Heavy	Very heavy
SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme

△ Seismic Instrument ○ Reported Intensity 🖌 Epicenter



PGV (cm/s)	0.1	0.2	0.5	1	2	5	10	20	50	100	200
Scale based on	Faenza a	nd Mich	elini (201	10, 2011)		Ve	ersion 1:	Processe	d 2023-	05-19T1	3:57:59
△ Seismic Instru	\star E	picenter	1								

Peak Ground Acceleration Map UNINA ShakeMap: Capo di Giano (PZ) May 14, 2023 07:28:46 UTC M2.7 N40.76 E15.49 Depth: 6.6km ID:17427r_acc







Irpinia Near-Fault Observatory

Ground motion (all events)



EARLY WARNING

PRESTo





ML 2.7, Capo Di Giano (PZ) 40.763, 15.487, 6.6 km 2023-05-14 07:28:46 (UTC)

FIRST ALERT AFTER 6.2 sec from T0 (3.5 sec from 1st pick, 7 stations) MAG error: -0.1 LOC_epi error : 3 km LOC_dep_error: 6.8 km

LAST ALERT AFTER 11.1 sec from T0 (8.4 sec from 1st pick, 13 stations) MAG error: -0.1 LOC_epi error : 1.5 km LOC_dep_error: 0.3 km



Final Message from PRESTo

Il sistema di Early Warning **PRESTo**, in fase di sperimentazione presso il <u>RISSC-Lab</u>, ha rilevato automaticamente un evento:

ML: 2.6 Data: 2023-05-14 07:28:46.48 (UTC) Località: Muro Lucano (PZ) Google Map

utilizzando 13 stazioni della rete ISNet - Irpinia Seismic Network.

La prima informazione su magnitudo e localizzazione dell'evento è stata disponibile al tempo:

```
2023-05-14 07:28:52.30 (UTC)
```

Cioè circa **3.5** secondi dopo il primo arrivo P rilevato alla stazione VDS3 al tempo:

2023-05-14 07:28:48.79 (UTC)





Real Time evolution PRESTO from CREW



Comparison of PRESTo estimates with ISNet bulletin values (dashed lines)

Data latency from PRESTo

m/s~n 2023-05-14 07:29:07.2	ISNet Real-Time		Num.	Station	Latency (s)
	Saves Several Saves	Ascal Stornareta	1	AND3	0,67
Ld 10s SSB3 [Z] N E	diad one Terme Pata	Ariano Carl	2	AVG3	0,57
Ld 0.0s BSC3 [Z] N E	Canta Sant'Agata Bathunto Aske	Candela at An	3	BEL3	1,16
Ld 0.8s Ld 2d22 LGS3 [Z] N E	Caserta de'Goti Ban Giorgio Grottano Maddaloni del Samo (VT) Marciano	arda Lacedonia Lavelo	4	BENI	0,68
Ld 0.8s BSE3 [Z] N.E	San Felce a Cancello	no Prigento puesto Metti Venosa (Sp	5	BSC3	-
Ld 15s 2P=2.5 4P=2.5 25=2.5 km=p2 SAU [7] N F	Giugliano in Arapola	Desa 1214 anos in Villare Palazzo Sar	6	CGG3	0,60
Ld 0.9s AND3.[Z] N.E.	Campania Campania Somma RISSC Vesuviana	Anta anta anta	7	CLT3	0,71
Ld 0.9s Lr 1.1s 2P=2.4 4P=#/# 25=2.3 km=18 CLT3 [Z] N E	Samo Mercato San Sevenno	2 GOTE Famo Acerenza d'Lice	8	CMP3	-
Ld 8.0s LiO3 [Z] N E	Greco Scatal Caya da Pacano G	Pierre SUDSCollano 2053 Bers 2009 Pietragalta com	9	COL3	0,57
LØ 8.0s LF 1d751	Castellammare d. Stabia =1.3 026 g Rove	Campagna 2015 Picerno Potenza	10	CSG3	0,71
Ld 109 2P=2.4 4P=2.4 2S=2.2 km=33 NSC3 [Z] N E	Battpagla	Ebos Caspardo Tas 2/2/20	11	LGS3	-
Ld 176 MARI ZI N. 5		Sertina State good grad	12	LIO3	-
Ld 0.8s 2P=2.6 4P=2.6 25+2.4 km=41 MNT3.[Z] N E		Abanda SADDirr Brierca Garaceo	13	MNT3	0,70
Ld 0.8s 2P=2.5 4P=5/a 2S=2.5 km=10 CSG3 [Z] N E		Oguatro Data Canada Patento Manucovetere	14	MRN3	0,64
Ld 156 2P=3.0 4P=3.0 2S=2.0 km=)2 SELB [Z] N E	Agrond	Parce Nazionare Sassano Padas Traveller	15	NAPI	1,70
Ld 0.5s	Castelanae	Valido de Calando Montesano Eginoso	16	NSC3	0,71
Ld 0.8s 2P=3.3 4P=1/a 23=3.3 km=10 VDS3 [7] N F		20 25-3 25-3 25-3 25-3	17	PGN3	0,63
Ld 0.9s 2P=2.0 4P=2.0 20=2.9 km=20 SNR3 [7] N F		243	18	PST3	0,68
Ld 11s 2P=2.4 4P=0/8 23=2.3 km=10 BEL3 [2] N_E	A State of the sector	*	19	RDM3	-
Ld 0.0s Lt 3m2t			20	RSF3	0,69
Ld 0.9s 2P=2.7 4P=4/8 23=2.7 Kite/is			21	SALI	1,73
Ld C.05 CMP3 [Z] N E			22	SCL3	-
LT ideh	20.3 1 Rd.5 Rd.5 Rd.5 Rd.5	.0 (15.3) (15.3) (15.3)	23	SFL3	0,71
Li Los 2942 3 4942 3 2542 2 km=33 PGM3 [2] N.E	07:28	07:29 07:29	24	SNR3	0,62
Le 1.06		ag 8.5	25	SRN3	0,63
Li 1.0s 2P=2.3 4P=2.8 23=2.7 km=27 [33133 12] N E		3	26	SSB3	0,81
		₽ ┛ ↓ ↓ ↓ ↓ ▲ ↓ ↓ _{2.5}	27	STN3	0,62
Lf L0s 2P=27 4P=2.5 23=2.6 km=53 CFU F			28	TEGI	1,59
Lf Lis TE/GI 171 N E			29	VDP3	-
Lt 0.8e		1.5	30	VDS3	0,71
Lt Lis			31	VGG3	0,95
QUAKE 653 15.4805 dx 0.8 km, 40.7694 dy 0	.9 km, 6.859 dz 1 km, 2023-05-14 07:28:46.48 MS:	2.6 MP: 2.6 BM: 2.6 (2.5 - 2.7)) 🔪 🛁			





QUAKE-UP Performances

Z m	/s^n Pause	Restart	2023-05-14 07:29:	00.0 ISNet	Capo_	di_Giano_ma	ain_14_0	5_2023		Quakel v0.1.	
	TARGET INT	TENSITY	TARC	SET LEAD TIME	74 -						
	No Damag (no shakin	ge ig)		20 sec	-38-2 n	No Damage No Damage No Damage no shaking) (weak shaking) (weak shaking) (No Damage Very Light Dama light shaking) (moderate shaking	ge Light Damage Moderate D ng) (strong shaking) (very strong Anaro irpino	amage Moderate-Heavy Damage shaking) (severe shaking)	Heavy Damage Very Heavy C (violent shaking) (extreme sh	Damage laking) di P
	07.25	07.28	MAGNITUDE	07.28 07.28	Ca	pua Casarta Sant'Ag	ata EBENEnto	Apice Flumeri	A16	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	Min
2.9				<mark>┶─┾╌┾</mark> ┼╌╄╌┝	N	Maddaloni Marcianise	del Sannio	Grottaminarda 59 Mirabella	BS Lacedonia	Lavello	Sala
Ld 0.0s		Atlentin			42.0 5	All		2 LOSS	asca	Melfi Pionero Venos	Ja Sp
Ld 0.0s		1 om/o=0.00 om/o^3			Giug	pliano in Afragola Nola	E842	SAL	ANDS	in Vulture	Palazzo San
Ld 0.0s)3 um/o=0.02 um/o^	2-002 SEV-020		RI	SS162dir Vesuviana	E841	MATENSCE	I RD.	23	Genza
Ld 0.0s		0			30.3 200	Torre del	Sarno Mercato San So Severino	<u> </u>	CS G3	FLB A	cerenza di Luca
Ld 0.0s		-	AND3-[Z]NE			Greco As Scafati	Cava de'	Giffoni Valle Pianc SNR	Bolliano VDSU	BELS	etragalla Lucan
Ld 0.0s		05-om/o=0.01-om/o^		-		Castellammare di Stabia	ZSE	Montecorvino Campagn Rovella	GOL3LVSCL	II sses	a <u>557</u>
Ld 0.0s Lf 1.0s)2			40.6	Sorrento	Bat	tipaglia Eboli	Canaan	DP3	
Ld 0.0s Lf 1.0s	1_PGV=-2.2 1_Comb=-2.	2				Anacapri		Altavilla Sep Silentina	ST3 CG	33 STN3	
Ld 0.0s Lf 1.0s	I_Pd=2.6 I_Pv=2.6 I_Pa	1 om/c=0.02 om/c^ =3.1 I_PGV=-5.5 I_1			-			Albanella	SRNS	Brienza Magsico	
Ld 0.0s Lf 1.0s		4 om/s=0.04 om/s^ =3.5 I_PGV=-3.4 i_			- 20.4			Capaccio Re	occadaspide	Sala MRNB Consilina Patemo M	areicovetere
Ld 0.0s Lf 1.0s							1	Agropoli Torchiara	Parco Nazionale	iano Padula	VGGB
Ld 0.0s Lf 1.0s	3.0 pm 0.00 Tu 0.2 [Pd=3.4 I_Pv=3.9 I_Pa	2 um/u 0.06 um/u =3.7 I <u>_PGV=3.0 I_</u> C]		Castel	labate Sessa Cilento	Vallo di Diano	Montesano la Marcellana	Spinoso
Ld 0.0s Lf 0.9s		0 0 om/o=0.02 om/o^ 3			30.2	14.2	14.8	Montecorice Salento	Lucania		20 km
Ld 0.0s Lf 1.0s		2 om/o=0.01 om/oA 2.3 1_PGV=-1.8 1_C	omp=BEL3TLZINE	alteritteriteriteriteriteriteriteriteriter	0.0				2.9		
Ld 0.0s Lf 1.0s	L_PGV=-1.0 L_Comb=-1.0	25 om/o=0.01 om/o^	COL3 (ZINE		10.0						
Ld 0.0s Lf 1.0s		=0.3 1_PGV=-3.4 1_]						
Ld 0.0s Lf 0.9s	I_PGV=-3.1 I_Comb=-3.1				20.0						
Ld 0.0s Lf 1.0s	Pd=0.9 _Pv=1.0 _Pa=	=1.4 <u>1_PSV=-1.3 _</u> C			30,0						
Ld 0.0s Lf 1.0s			STN3 [Z]NE		40.01						
Ld 0.0s Lf 0.9s	[_PGV=-3.0]_Comb=-3.1	D D D D D D D D D D D D D D D D D D D	SRN3 [Z]NE		1	14.3	14.3	15.0	15.2 15.5	15.8	13.0
Ld 0.0s Lf 1.0s			MRN3 (Z]NE								
Ld 0.0s Lf 1.0s			Wecs [Z]NE								

QUAKE Q: 0 lon: 15.4717 dx(km): 1.6 lat: 40.7679 dy(km): 1.5 dep: 3.086 dz(km): 2.2 OT: 2023-05-14T07:28:46.60 M: 2.9 M_min: 2.5 M_max: 3.3

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FIRST ALERT AFTER 3 sec from T0 (2 sec from 1st pick, 3 stations) MAG error: 0.4 LOC_epi error : 8.3 km LOC_dep_error: 6.7 km

LAST ALERT AFTER 13 sec from T0 (12 sec from 1st pick, 3 stations) MAG error: 0.4 LOC_epi error : 1.5 km LOC_dep_error: 2.2 km

Irpinia Near-Faul Observatory

EARLY WARNING

QUAKE-UP Performances

The first location and magnitude estimates are available 3 seconds after the O.T. Both epicentral location and magnitude are quite stable in time, while the epicenter depth reaches a stable value 9.5 seconds after the O.T.



Offline Performances of SAVE@VDS

On-Site estimates of Intensity, Alert Level, Magnitude and Distance as provides by SAVE@VDS station (epicentral distance) 8.3km), through the playback of recorded waveforms. All the estimates are obtained using the vertical component of acceleration waveforms and using the first 3 seconds of recorded P-wave signal.



The system was able to compute both the Pd amplitude and the Tauc parameter, and was able to provide estimates of magnitude, distance and intensity ranges.

The estimated intensity (through the Pd) was III, which is consistent with the observed value.

The event was correctly classified as a **small magnitude** event **nearby** the station.

IN

ISNet EW-APP

ISNET EWApp received the alerts from PRESTo for the following events during the sequence:

- Mag: 2.6, Time: 2023-05-14 07:28:46.48
- Mag: 1.4 (PRESTo Mag: 1.6), Time: 2023-05-14 07:39:26.63
- Mag: 1.5, Time: 2023-05-20 12:15:00.09
- Mag: 1.9, Time: 2023-05-20 23:06:18.87

The pictures show the screenshot of the app, on a smartphone located at Naples (epicentral distance of about 110 km), during the first two earthquakes.

5 smartphones received the alerts for the first two events and
6 smartphones received it for the latest two. The smartphones
were located between Naples, Sorrento and Palomonte.
The smartphones received the warning within an average time
ranging between 0.8 and 1.7 s, for the different events.





Irpinia Near-Fau Observatory



Seismic sequence and CROP model



The area of the sequence has been investigated in the past by the **CROP-04** exploration campaign. We found locations and focal mechanisms compatible with the NEBF of the Irpinia area, an antithetic structure which is believed to delimitate the fluid reservoir and the graben related to the 1980 Irpinia earthquake. The sequence extends for 2-3 km below the San Fele area.

From Amoroso et al. (2017)









RISSC-Lab: Laboratorio di Ricerca in Sismologia Sperimentale e Computazionale Università degli studi di Napoli Federico II

Useful Links:

ISNet <u>http://isnet.unina.it/</u>

ISNet Bulletin <u>http://isnet-bulletin.fisica.unina.it/cgi-bin/isnet-events/isnet.cgi</u>

CREW: https://lccepos.fisica.unina.it/



