



CONVEGNO  
**SCARTI MINERARI:  
DA RIFIUTO A RISORSA**

6/7 ottobre 2022  
📍 Stava di Tesero (TN), Italy

fondazione  
**stava**1985 ONLINE



**ISPRA**  
Istituto Superiore per la Protezione  
e la Ricerca Ambientale



**GEAM**

ASSOCIAZIONE GEORISORSE E AMBIENTE



ASSOCIAZIONE  
NAZIONALE  
INGEGNERI  
MINERARI

**AGI** Associazione  
Geotecnica  
Italiana

# Dalla caratterizzazione al riuso sostenibile dei sedimenti: il contributo dell'ingegneria geotecnica per un caso emblematico italiano

**Claudia Vitone**, Federica Cotecchia, Rossella Petti, Francesca Sollecito



Politecnico  
di Bari

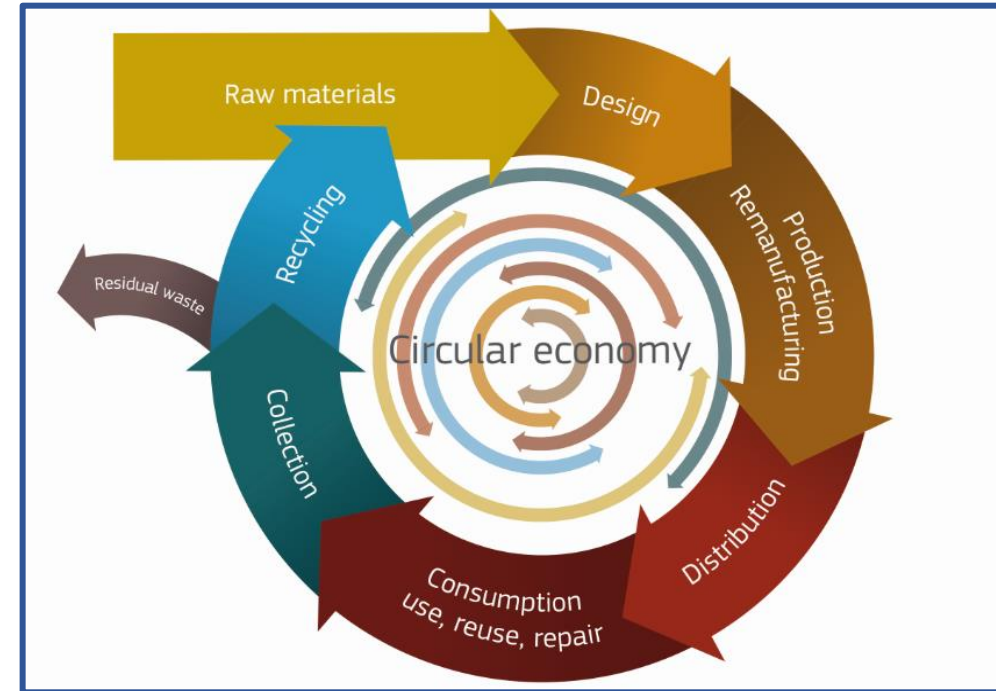
**AGI** Associazione  
Geotecnica  
Italiana

Michael Ploetze, Alexander M. Puzrin

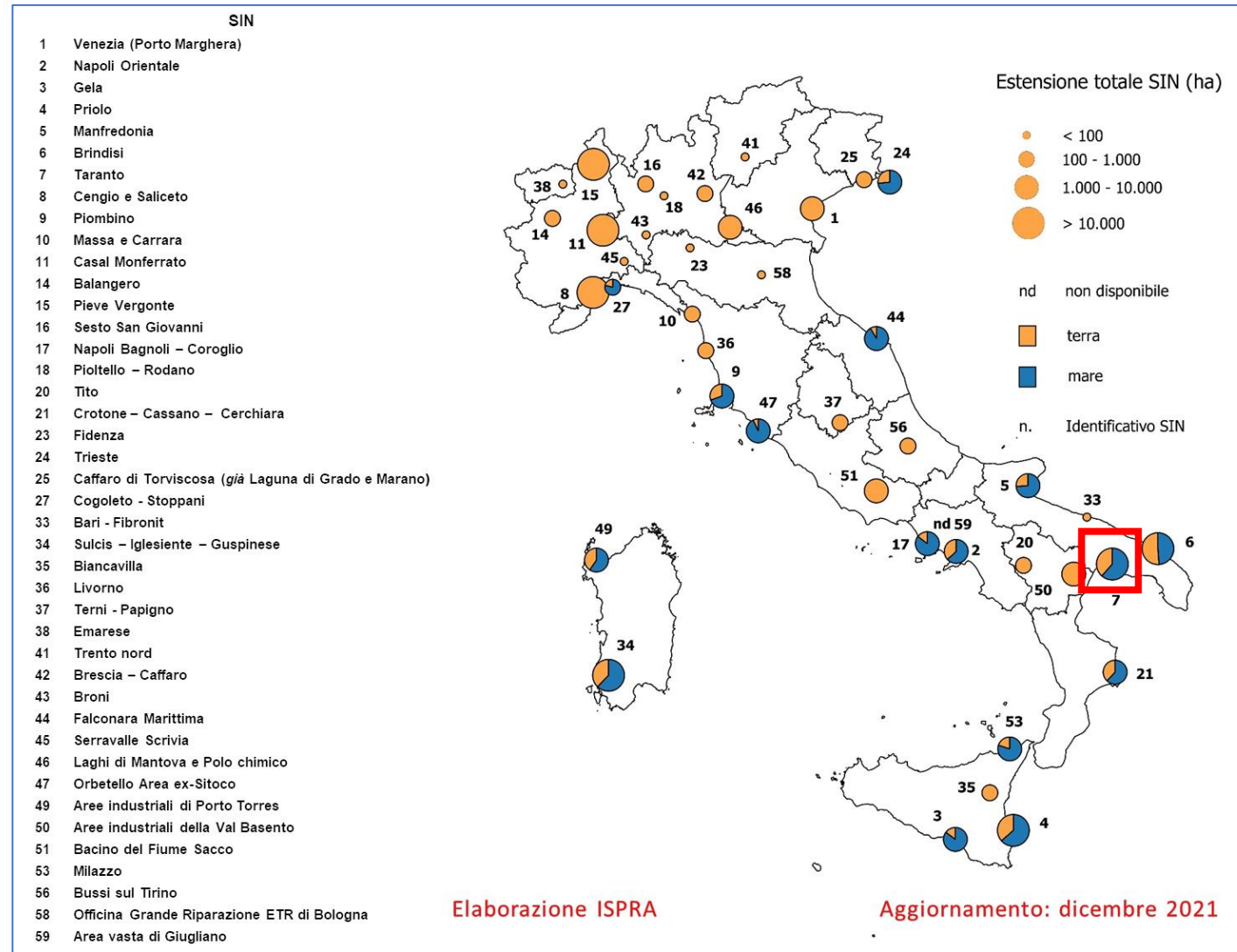
**ETH**zürich



## sedimenti dragati



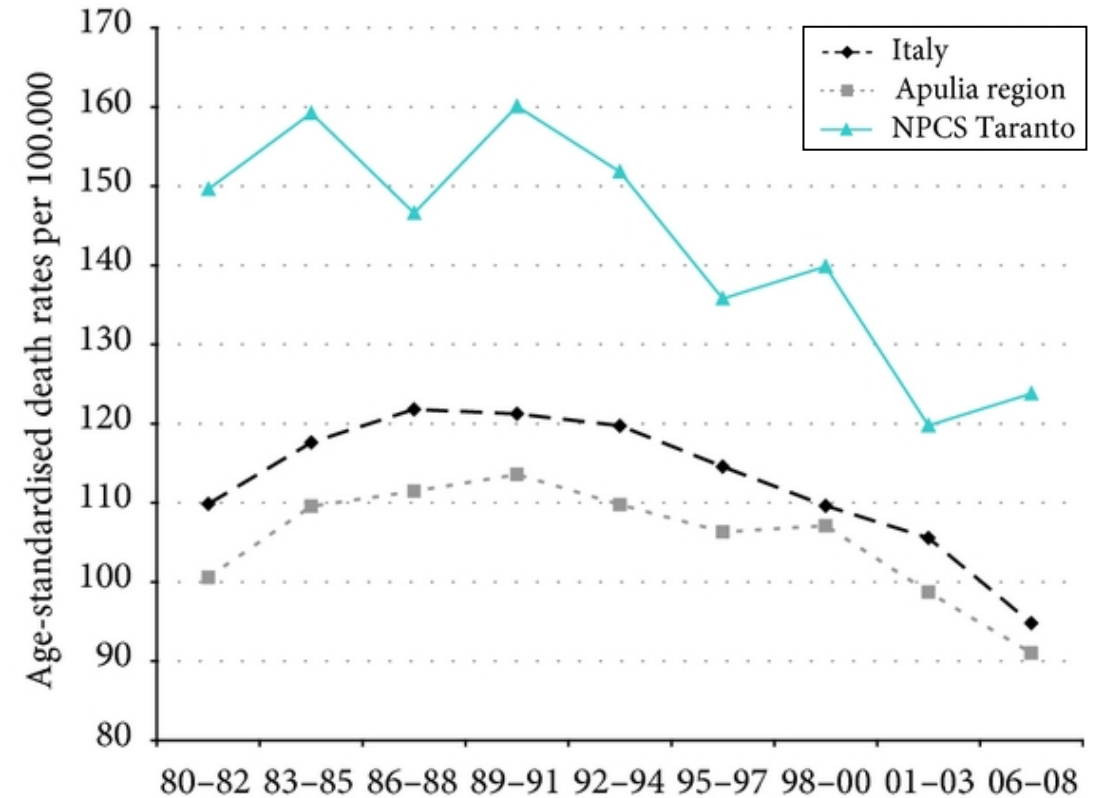




<https://www.mite.gov.it/pagina/siti-contaminati-di-interesse-nazionale-sin>



Epidemiological studies: dramatic mortality excess (all causes of death, all cancers, lung cancer, cardiovascular and respiratory diseases, etc.) in the residents around the industrial district (Pirastu et al., 2013). **Breast milk** sampled in nursing women living in Taranto has **dioxin content 10–40 times** higher than the tolerable intake values from the World Health Organization (Bianco et al., 2013).



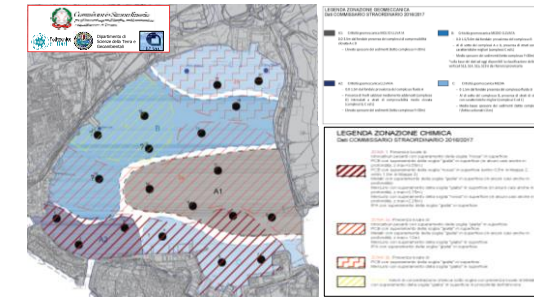
(Pirastu et al. 2013)



# Dalla caratterizzazione al riuso sostenibile dei sedimenti: *il contributo dell'ingegneria geotecnica per un caso emblematico italiano*

- **Il Mar Piccolo a Taranto: che modello modello concettuale di sito?**

- i. Contesto e approccio
- ii. Risultati



- **Focus sui sedimenti marini: da scarto a risorsa?**

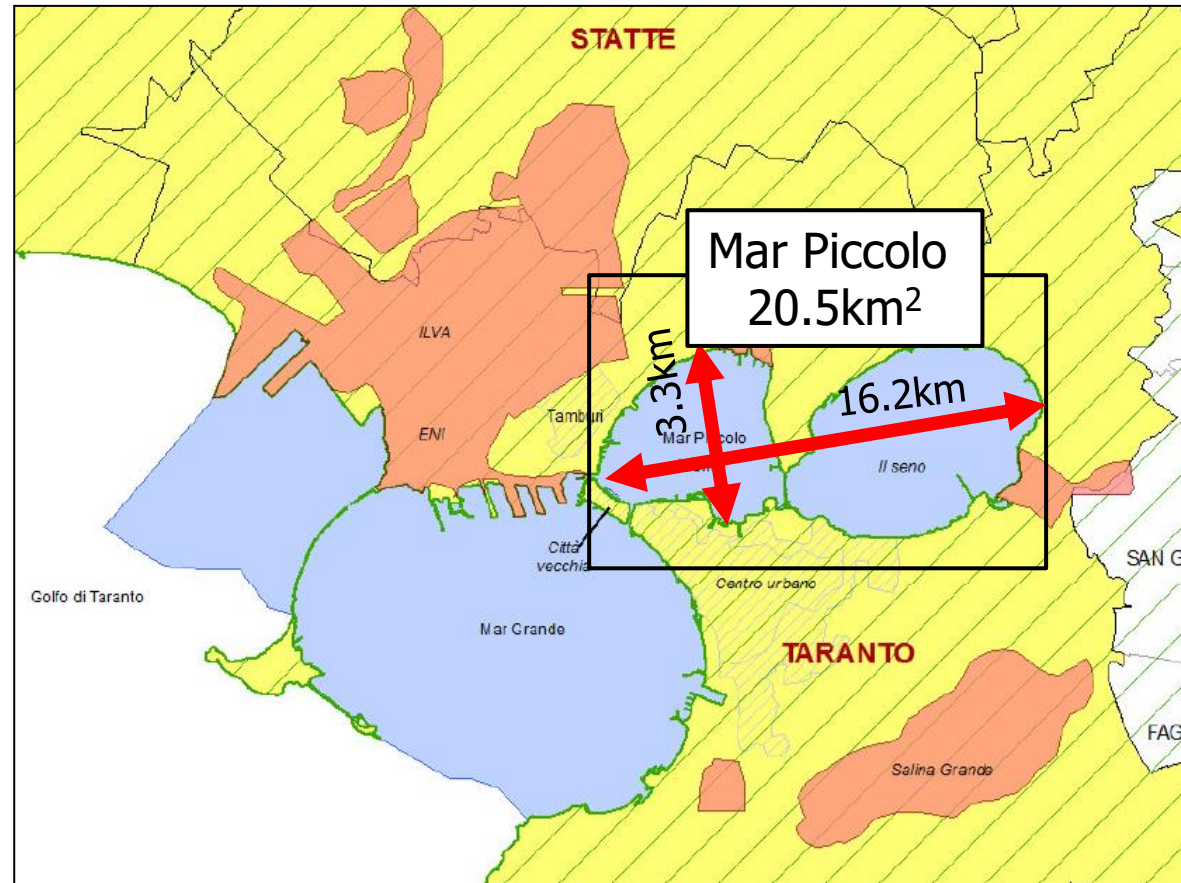
- I. Opzioni per il riuso
- II. Le complessità della caratterizzazione





Area di **crisi ambientale complessa**: circa 560km<sup>2</sup> - 265.837 abitanti

Area SIN: circa 120km<sup>2</sup> (2/3 **SIN mare**)



<http://www.commissariobonificataranto.it/>



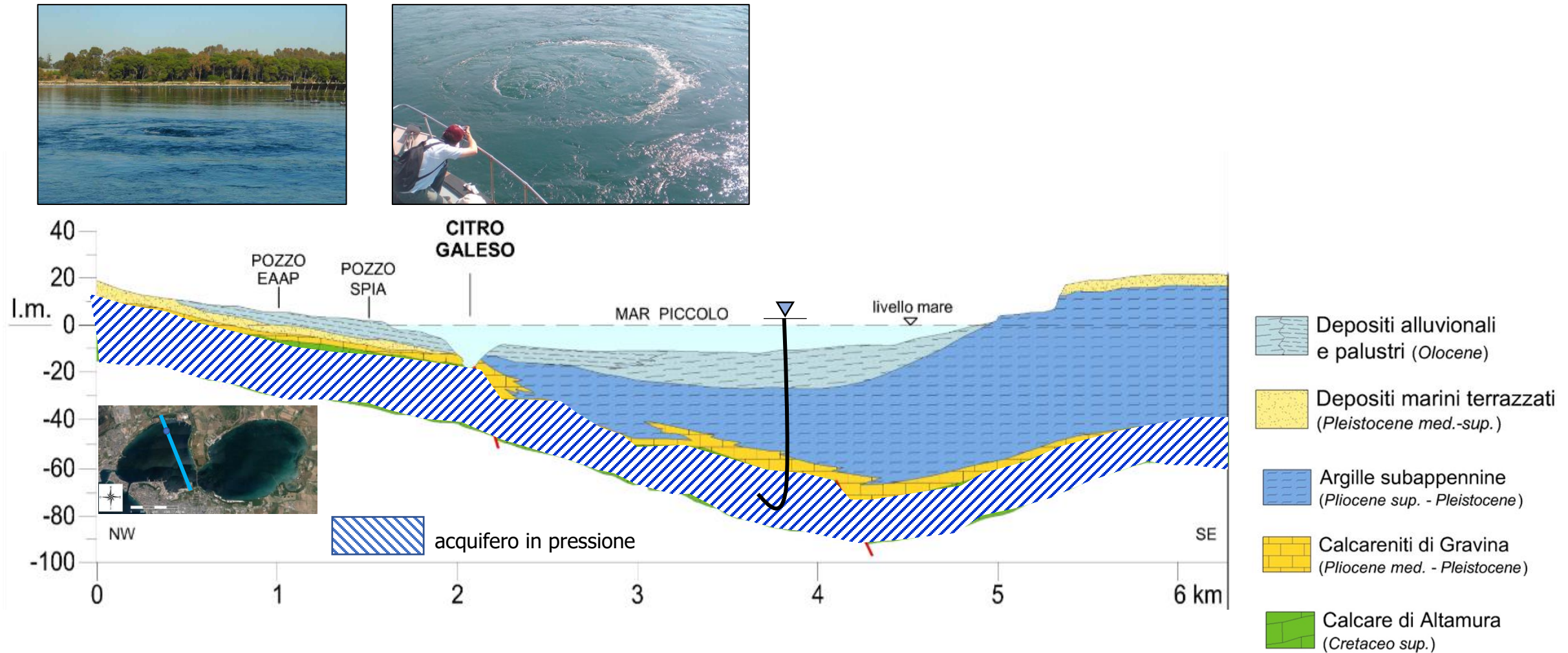








## assetto geologico



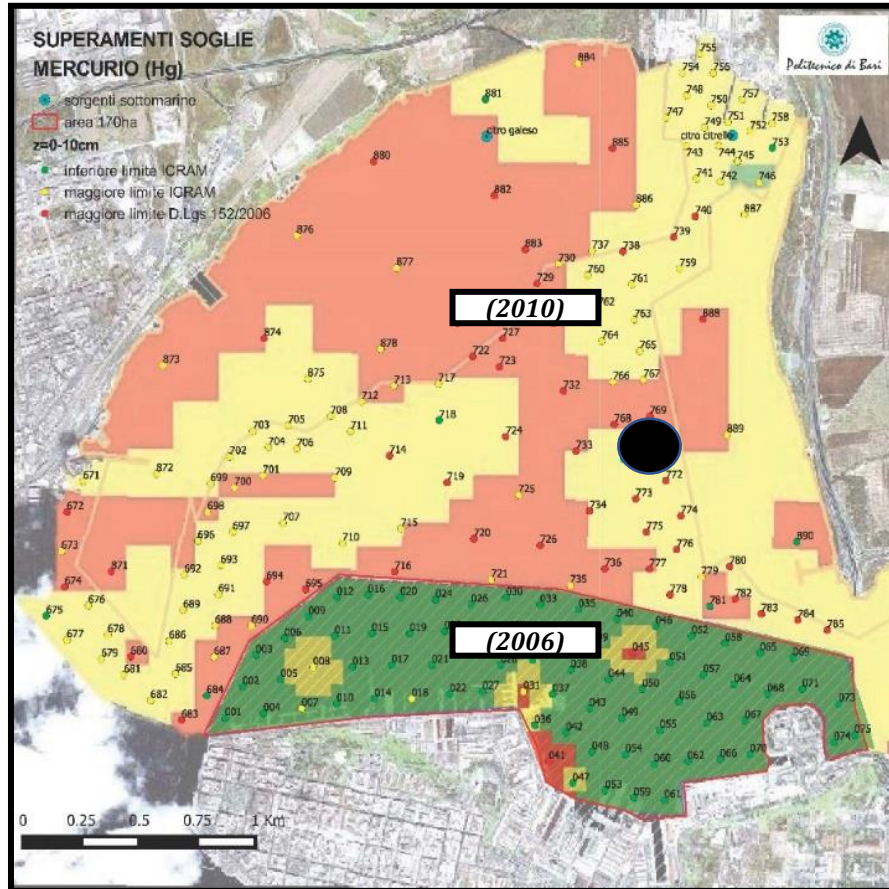
(V. Cotecchia 1991, 2017)



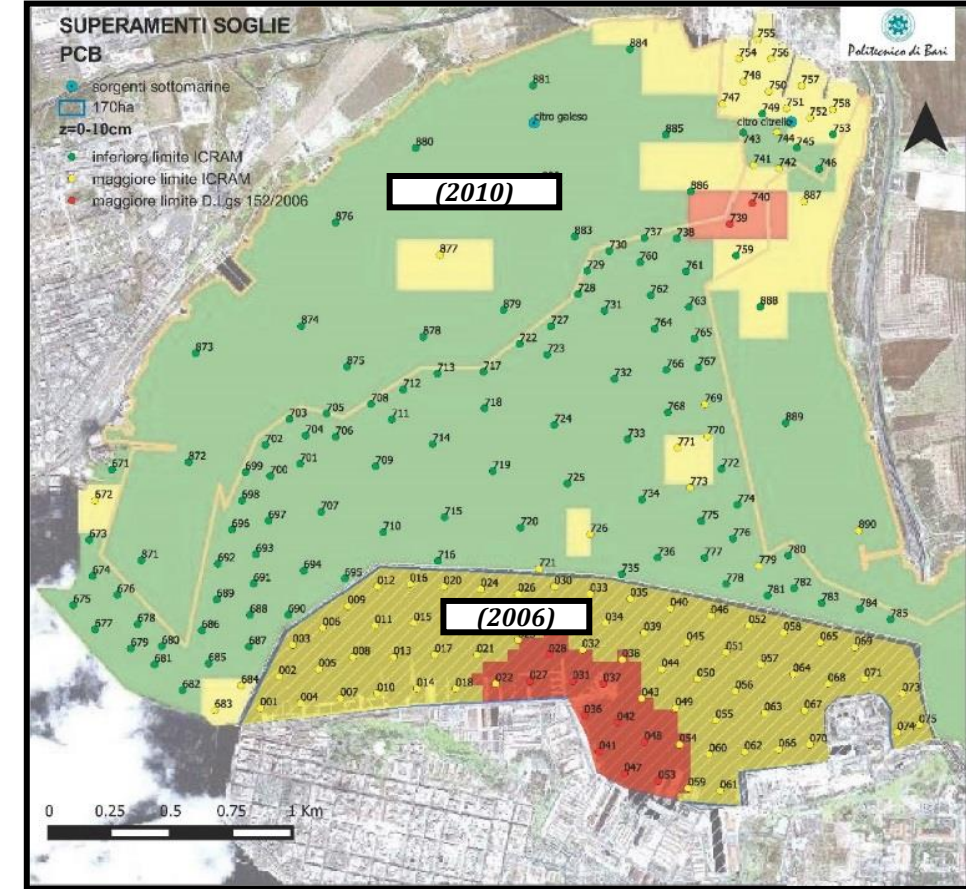
# il Mar Piccolo: complessità ambientale

primi studi sullo stato di contaminazione (2.5m dal fondale)

## Mercurio



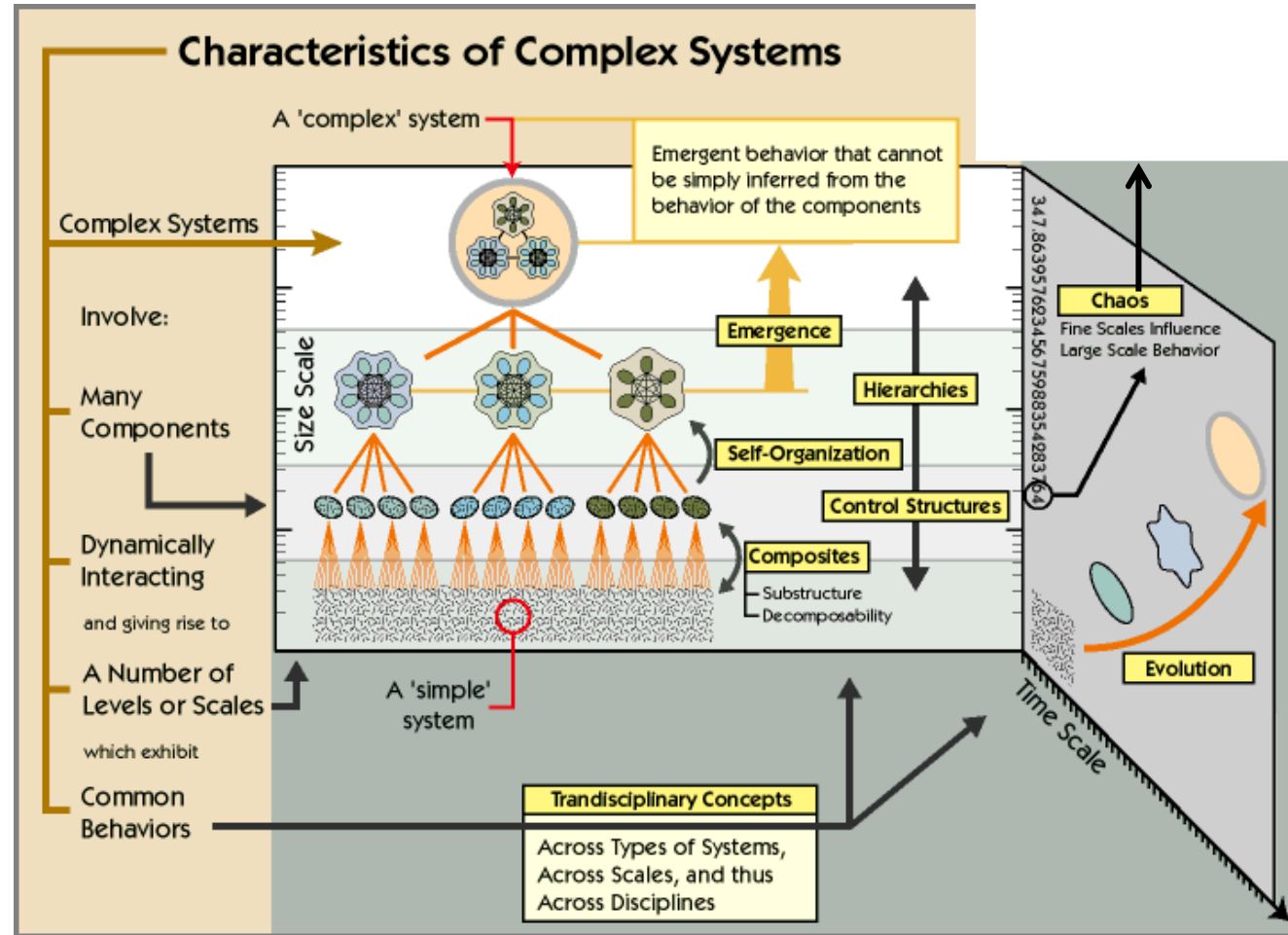
## PCB





complessità





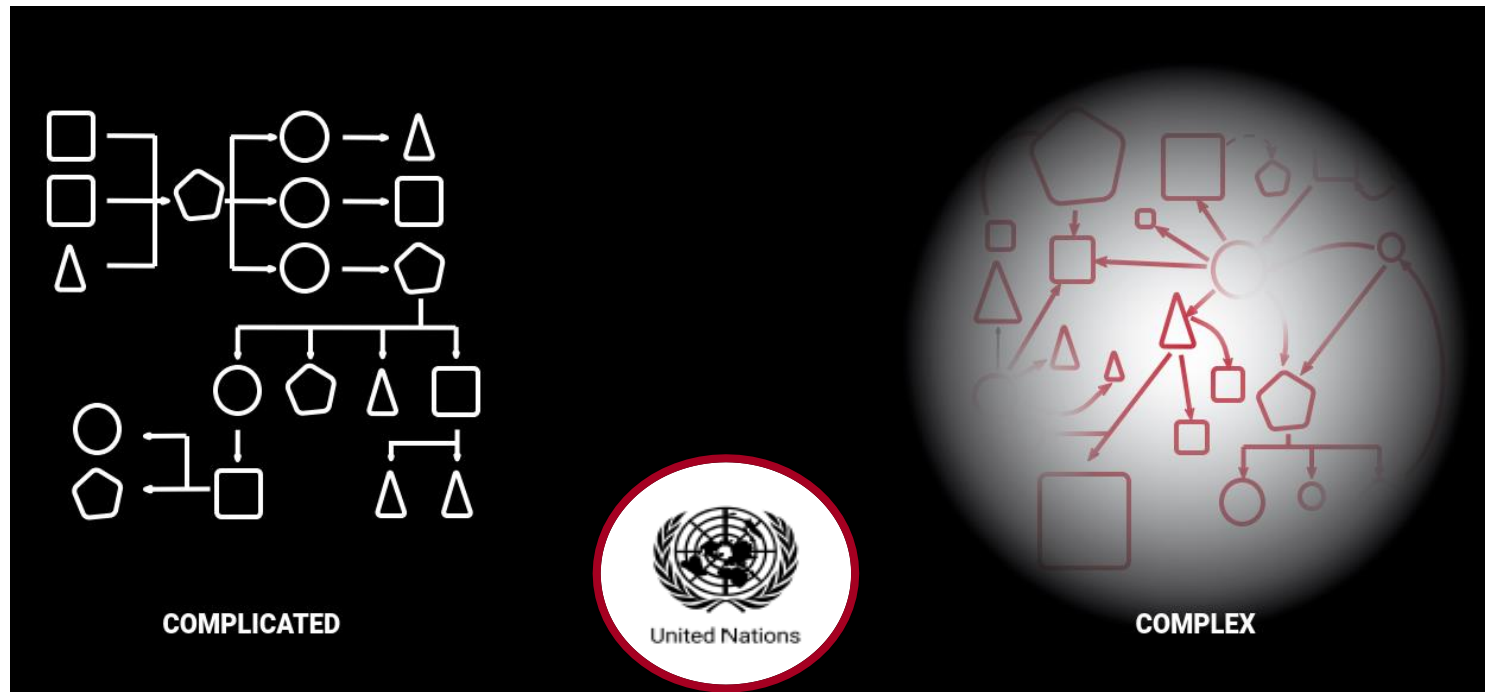
«*Reductionism* can be still applied to *complex systems*.»

(Tracing complexity theory, Ferreira 2001)



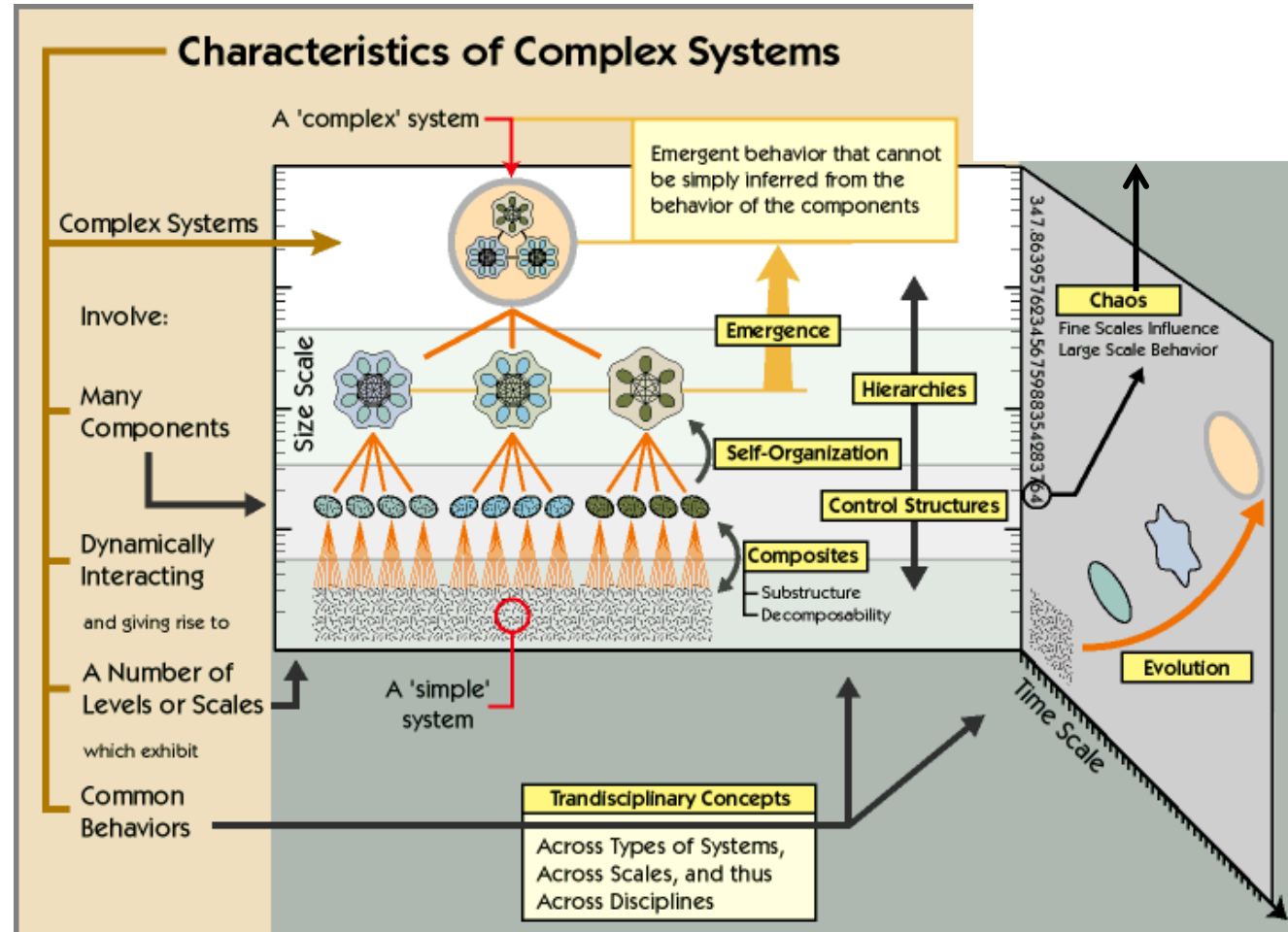
## It's complex – let's deal with it

### ISSUE



<https://www.undrr.org/publication/global-assessment-report-disaster-risk-reduction-2019>





(Tracing complexity theory, Ferreira 2001)



I **sistemi caotici** non sono sensibili alle **condizioni iniziali**. Sono sistemi ad **effetto farfalla**.



*«The Flap of a Butterfly's Wings in Brazil can set off a Tornado in Texas»*

(Lorenz 1972)

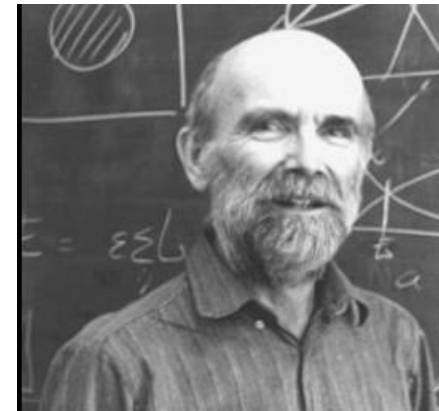
## Chaos, Complexity, and Entropy A physics talk for non-physicists

Michel Baranger

*Center for Theoretical Physics, Laboratory for Nuclear Science and Department of Physics  
Massachusetts Institute of Technology, Cambridge, MA 02139, USA*

and

*New England Complex Systems Institute, Cambridge, MA 02138, USA  
MIT-CTP-3112*



*«To summarize, **chaos destroys our reductionist dream**, the dream that we  
have absolute power if we only know enough about the details»*

**sistema complesso? sistema caotico?**



# l'indagine più recente (2015-2019)

Decreto Legge - DL 5/01/2015 – «si riconosce *la straordinaria necessità ed urgenza di applicare misure per la mitigazione del rischio, lo sviluppo, il rilancio della città di Taranto e le aree limitrofe.*»

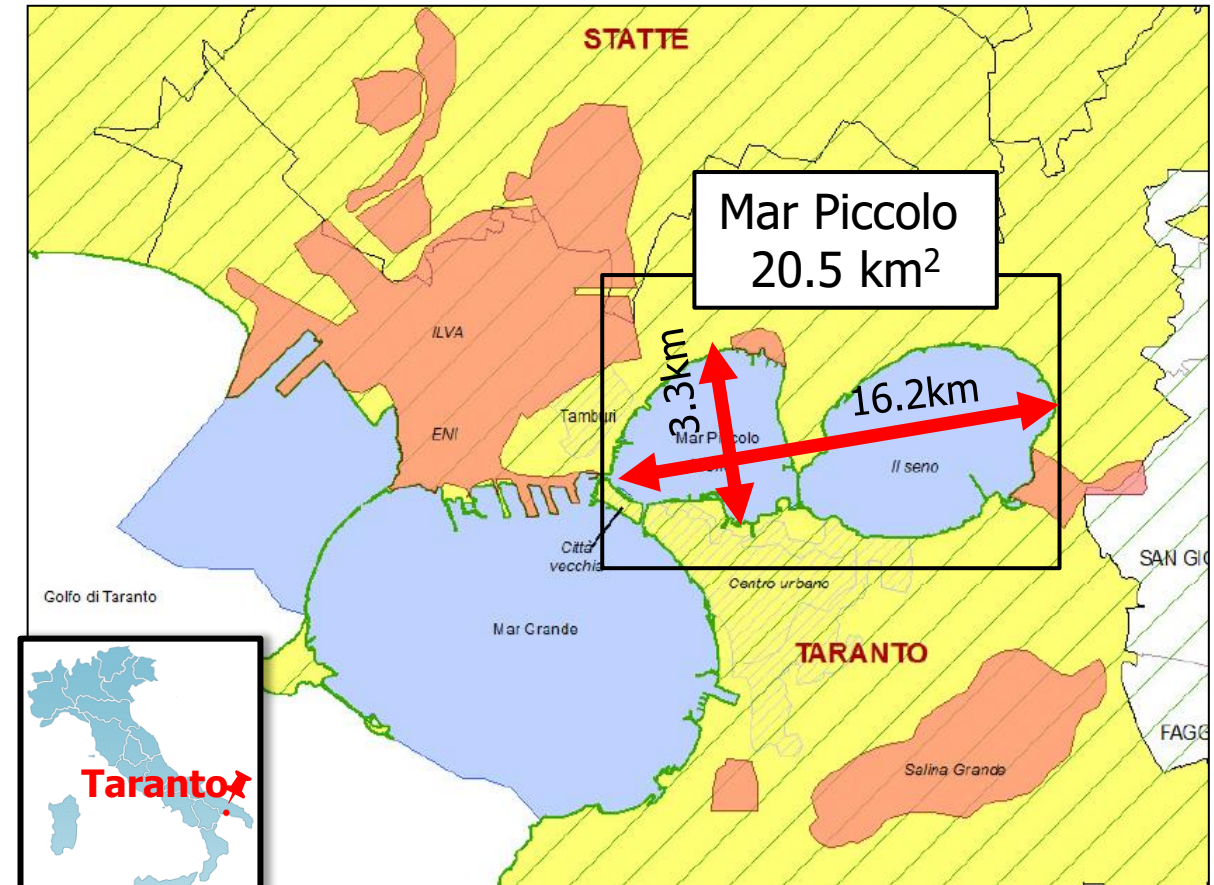


*Dott.ssa Vera Corbelli*

*Commissario Straordinario di Governo per gli interventi urgenti di bonifica, ambientalizzazione e riqualificazione di Taranto (D.P.C.M. 8 luglio 2014)*

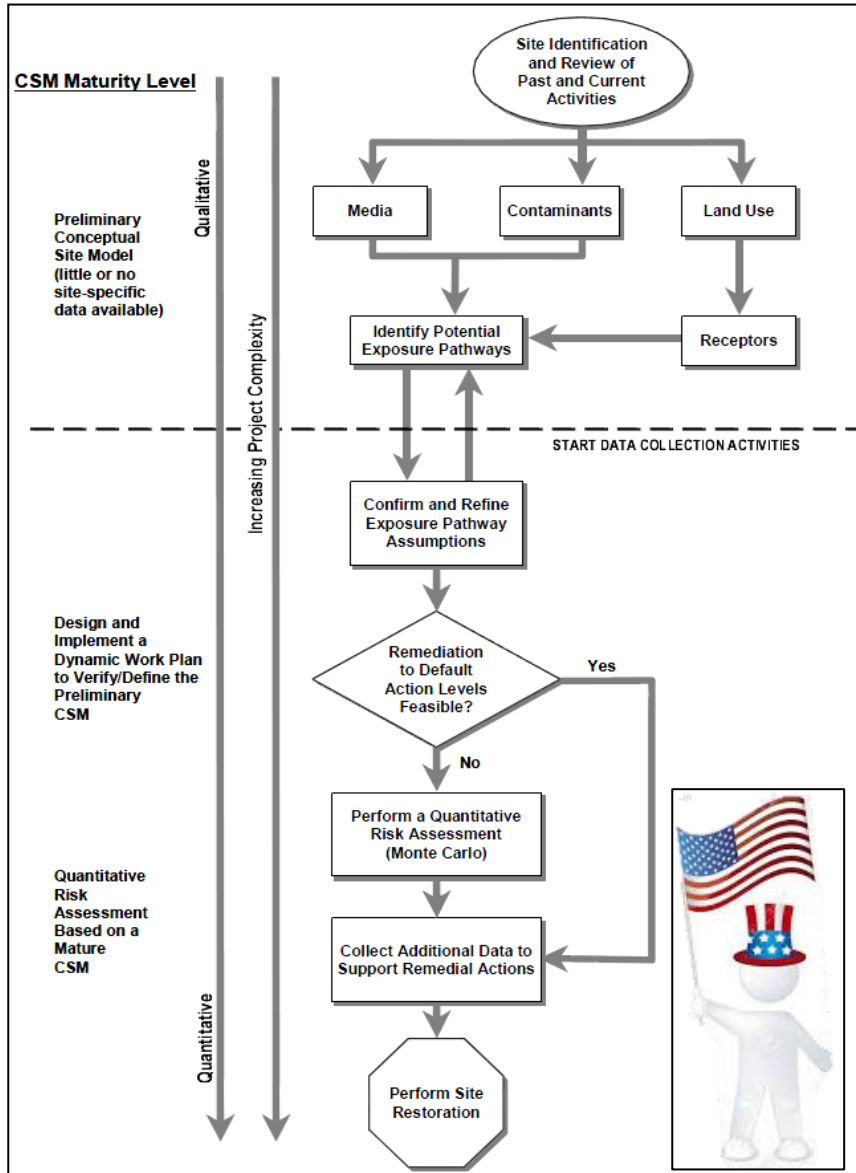


**SIN: 116.93 km<sup>2</sup>**  
•Aree a terra: 43.83 km<sup>2</sup>  
•Aree marine: 73.10 km<sup>2</sup>



<http://www.commissariobonificataranto.it/>





(USEPA 2005)

Modello Concettuale di Sito (CSM): modello dinamico di rappresentazione dei processi fisici, chimici, biologici che occorrono nel sito e dei recettori ambientali.

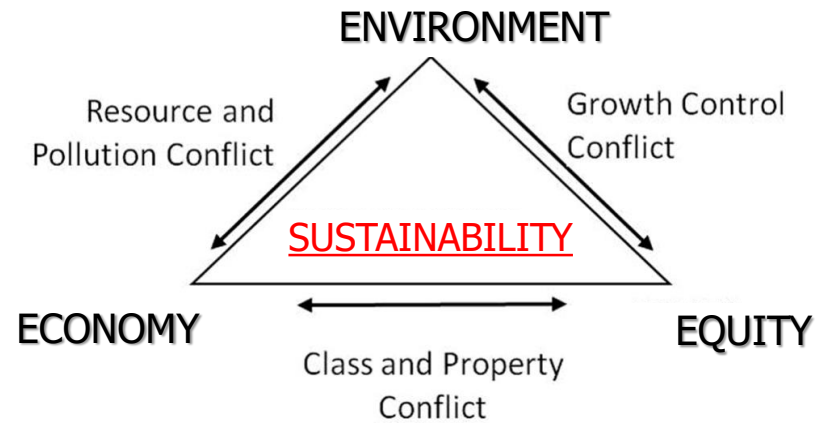
### 3.4.2.1 Geotechnical Properties

Geotechnical parameters strongly affect the physical disposition characteristics of the sediment bed and therefore affect the fate and transport of contaminants over space and time.



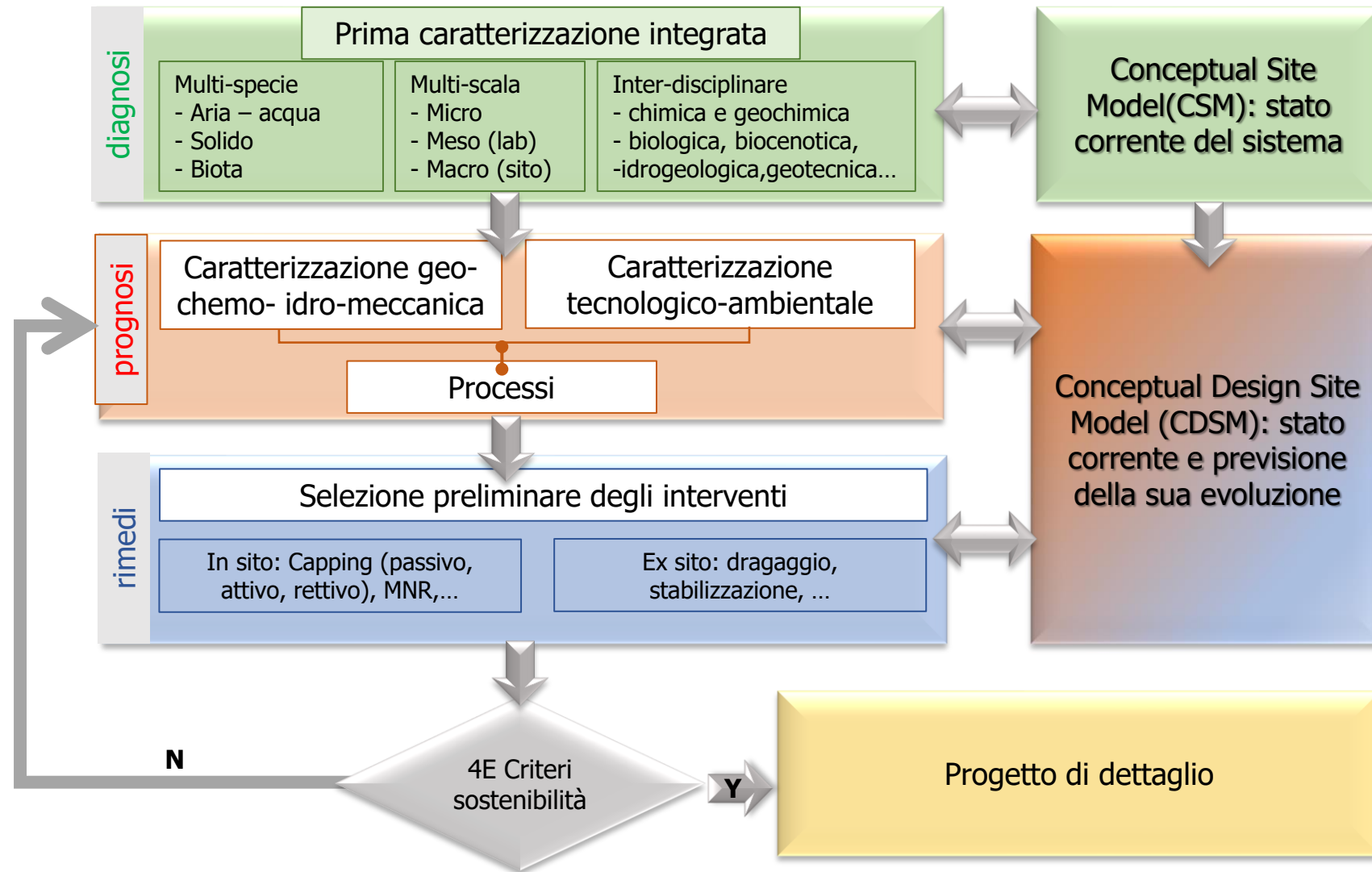
(ITRC, 2014; Canadian Council of Ministers of the Environment, 2016)





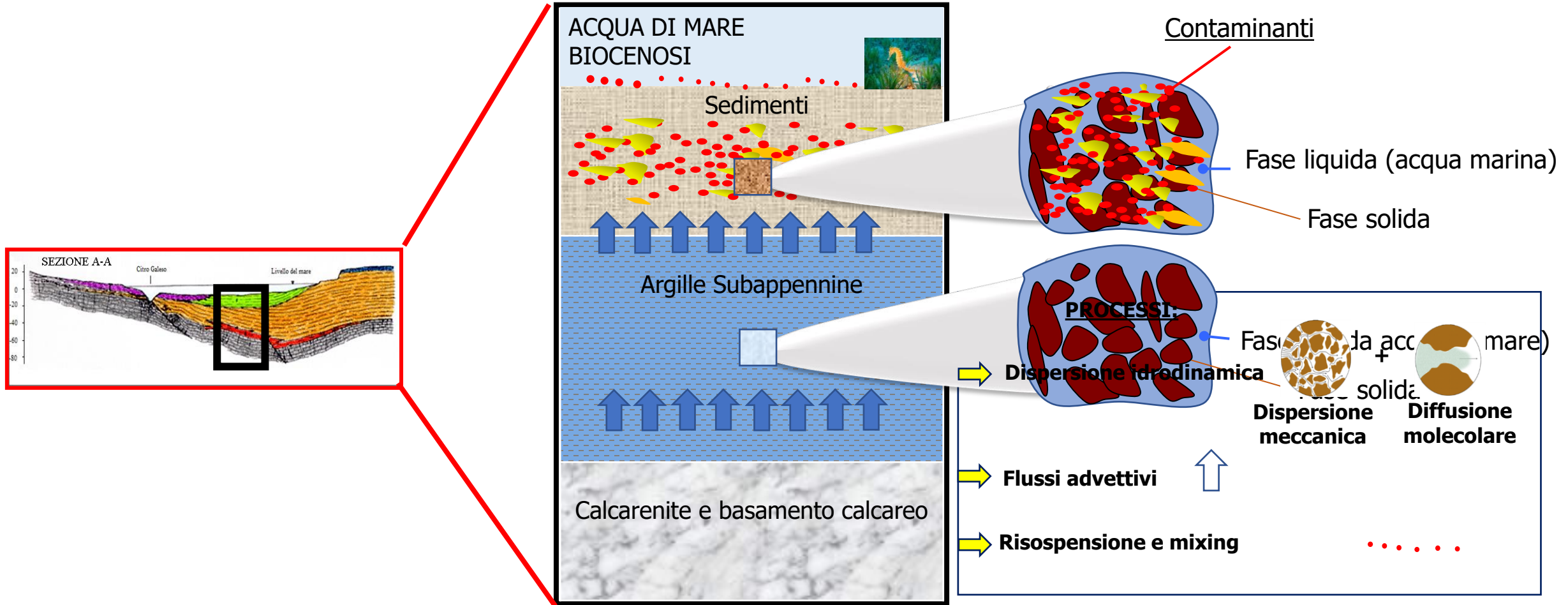
(World Summit on Social Development, 2005)





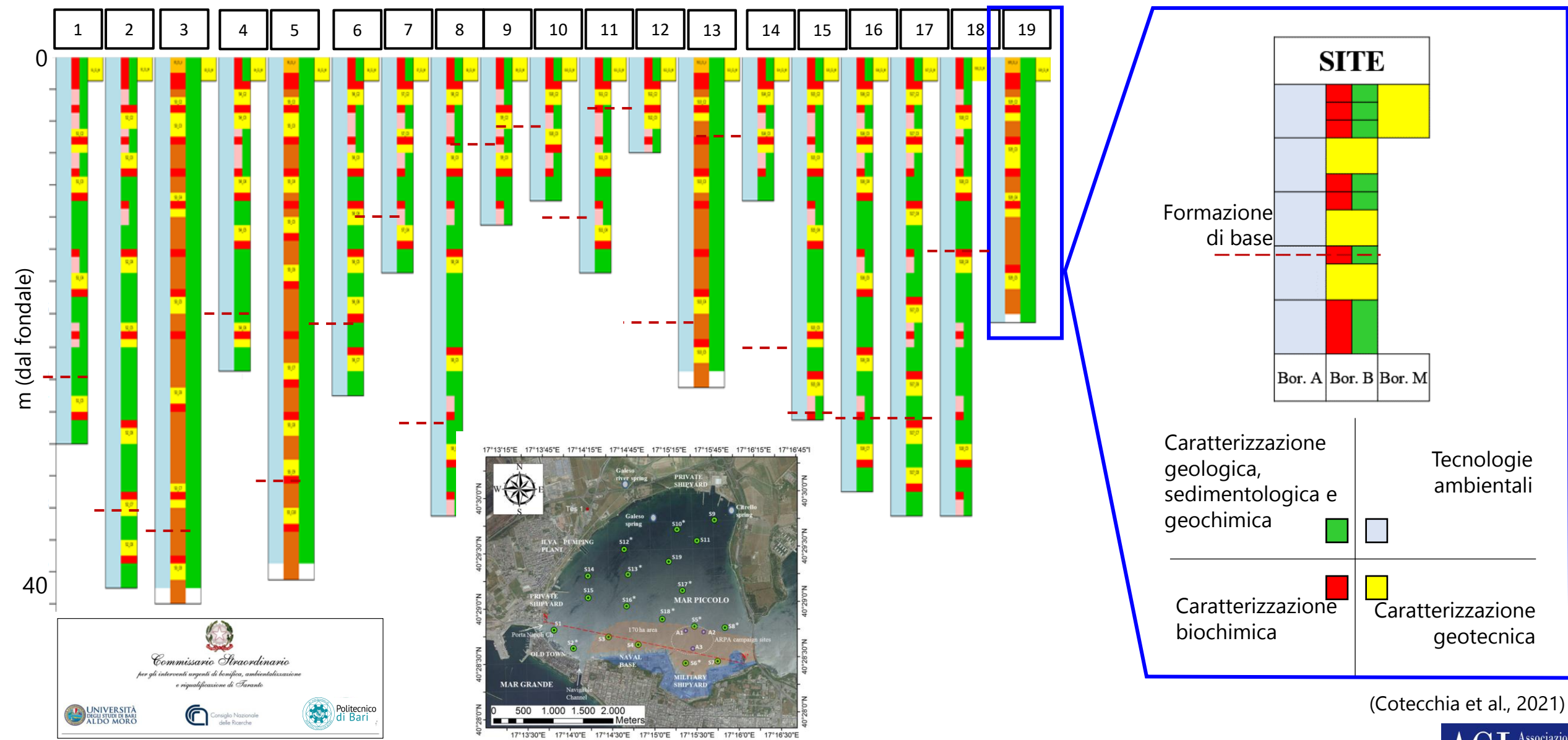


## stato attuale del sistema





# sedimenti marini: indagine in-sito



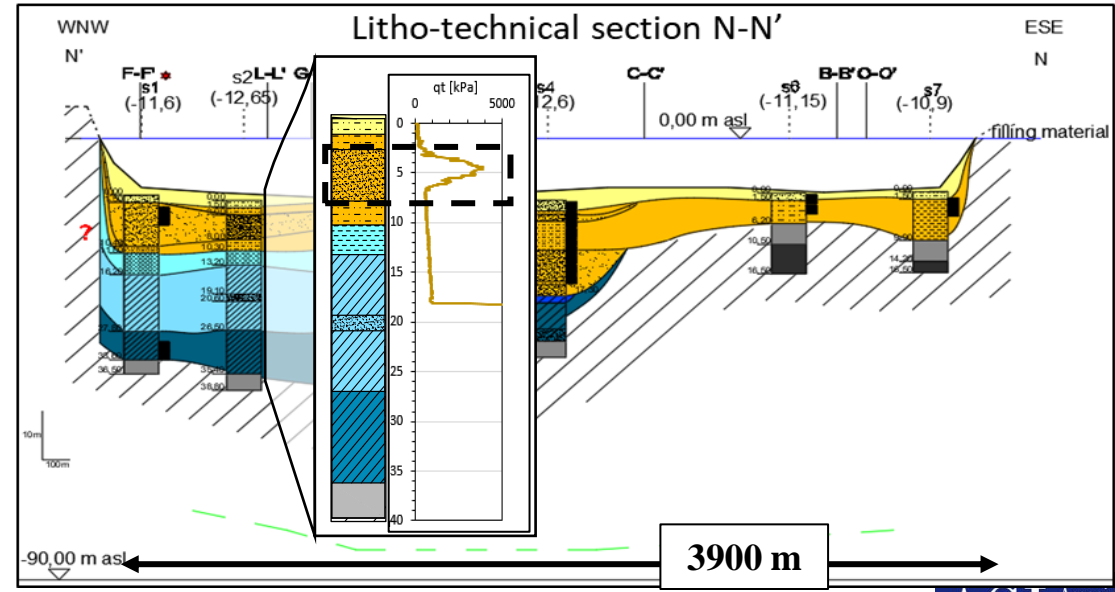
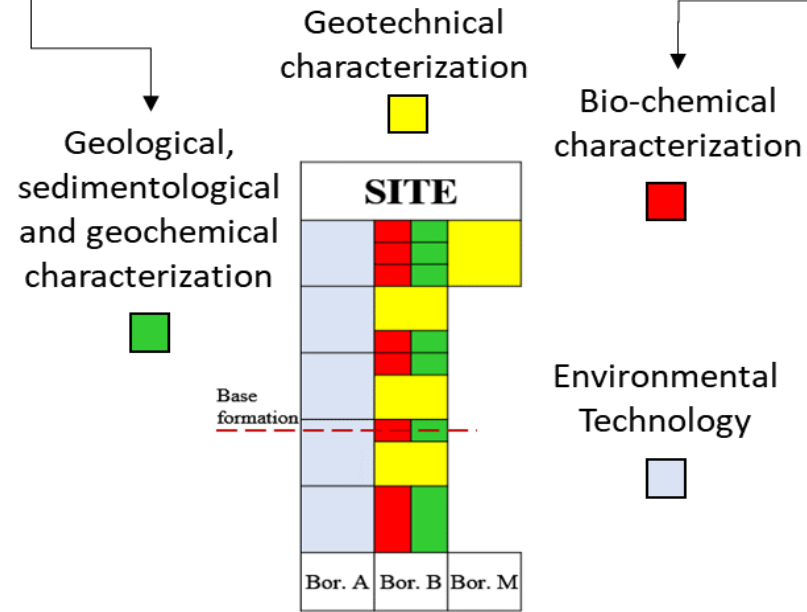
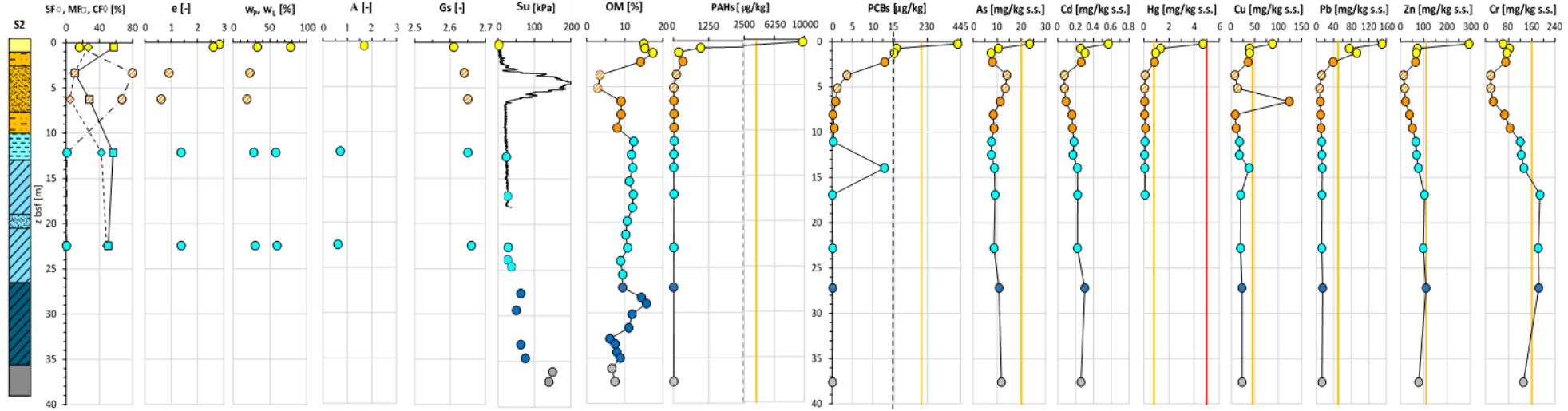
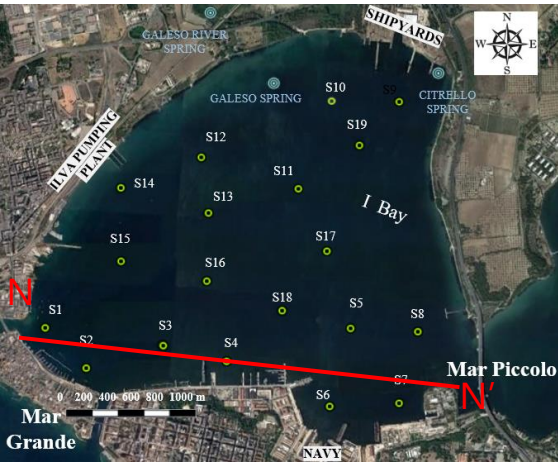
(Cotecchia et al., 2021)







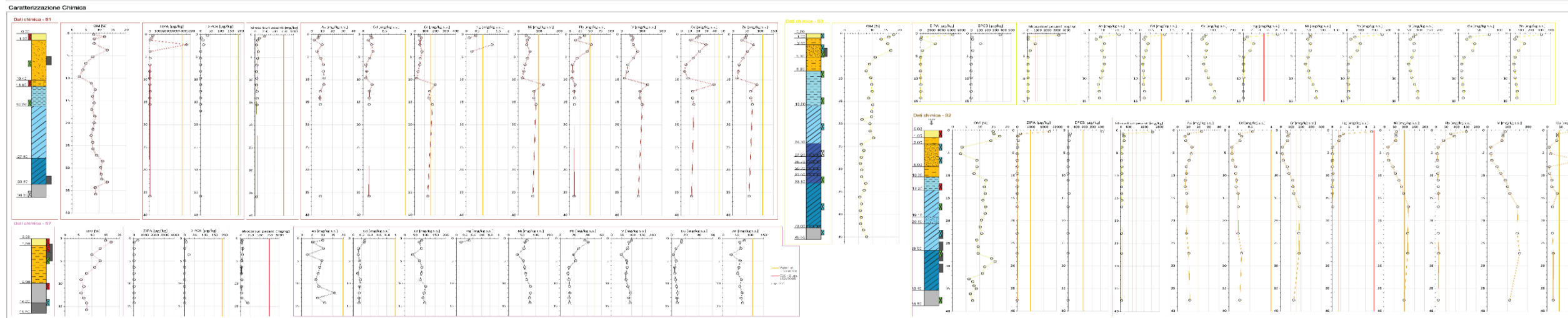
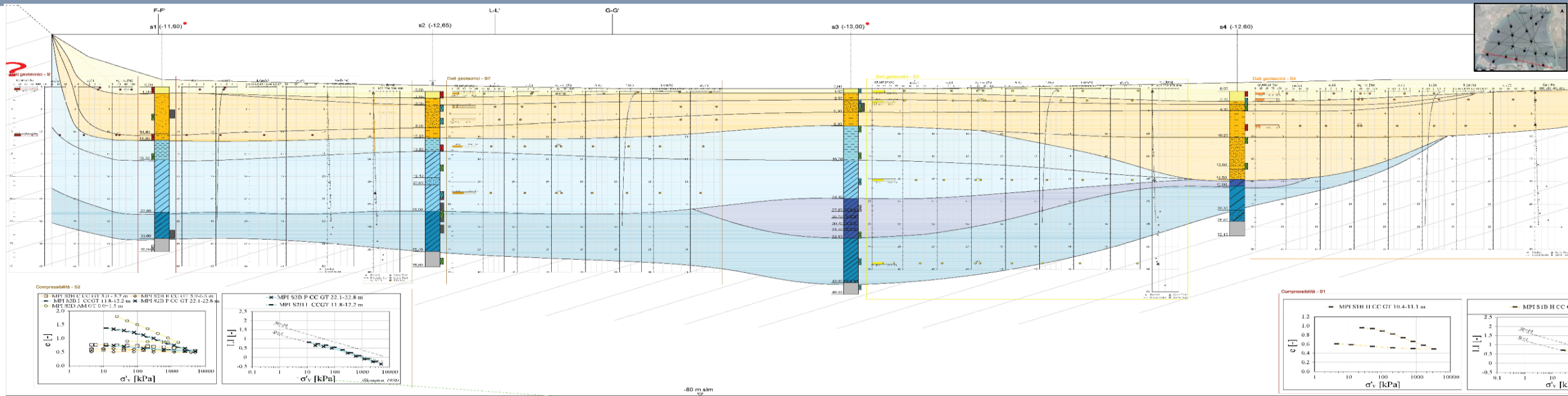
# costruzione del CDSM: verticali multi-disciplinari



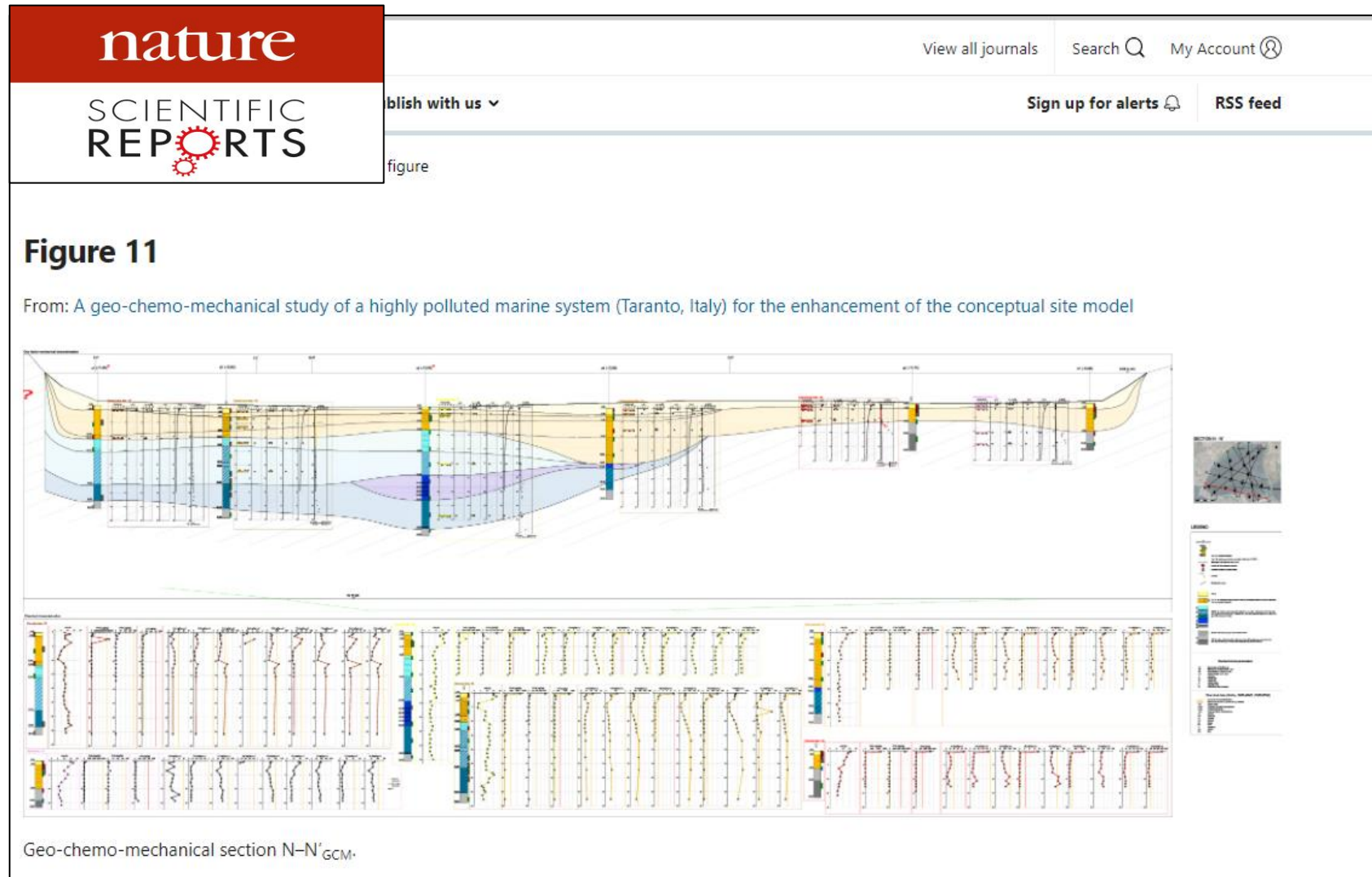
(Cotecchia et al., 2021)



# costruzione del CDSM: sezioni multi-disciplinari





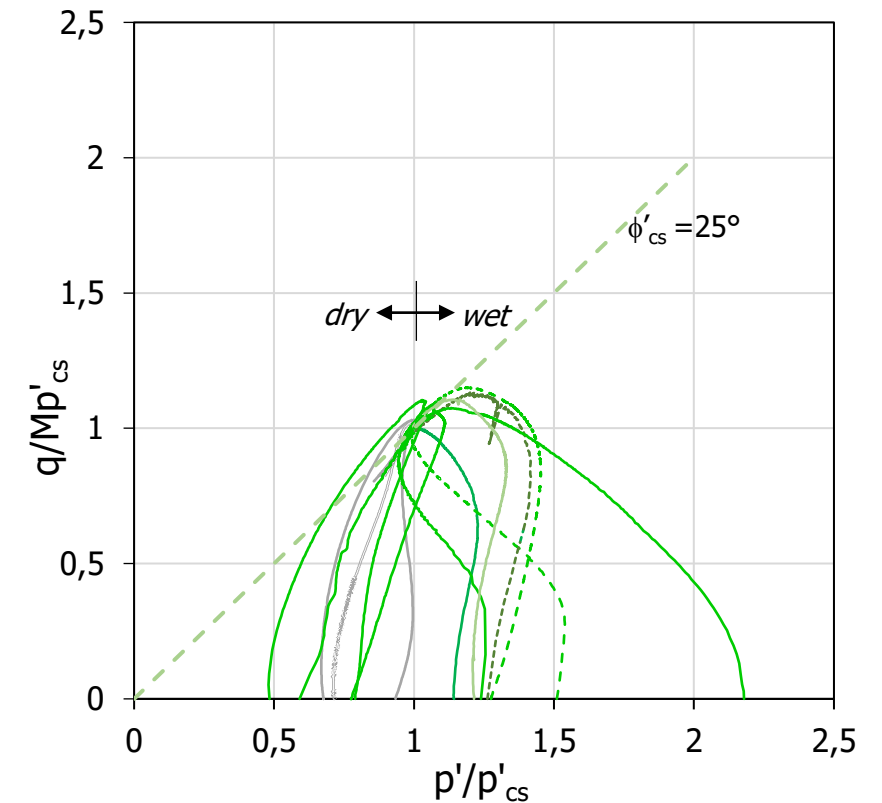
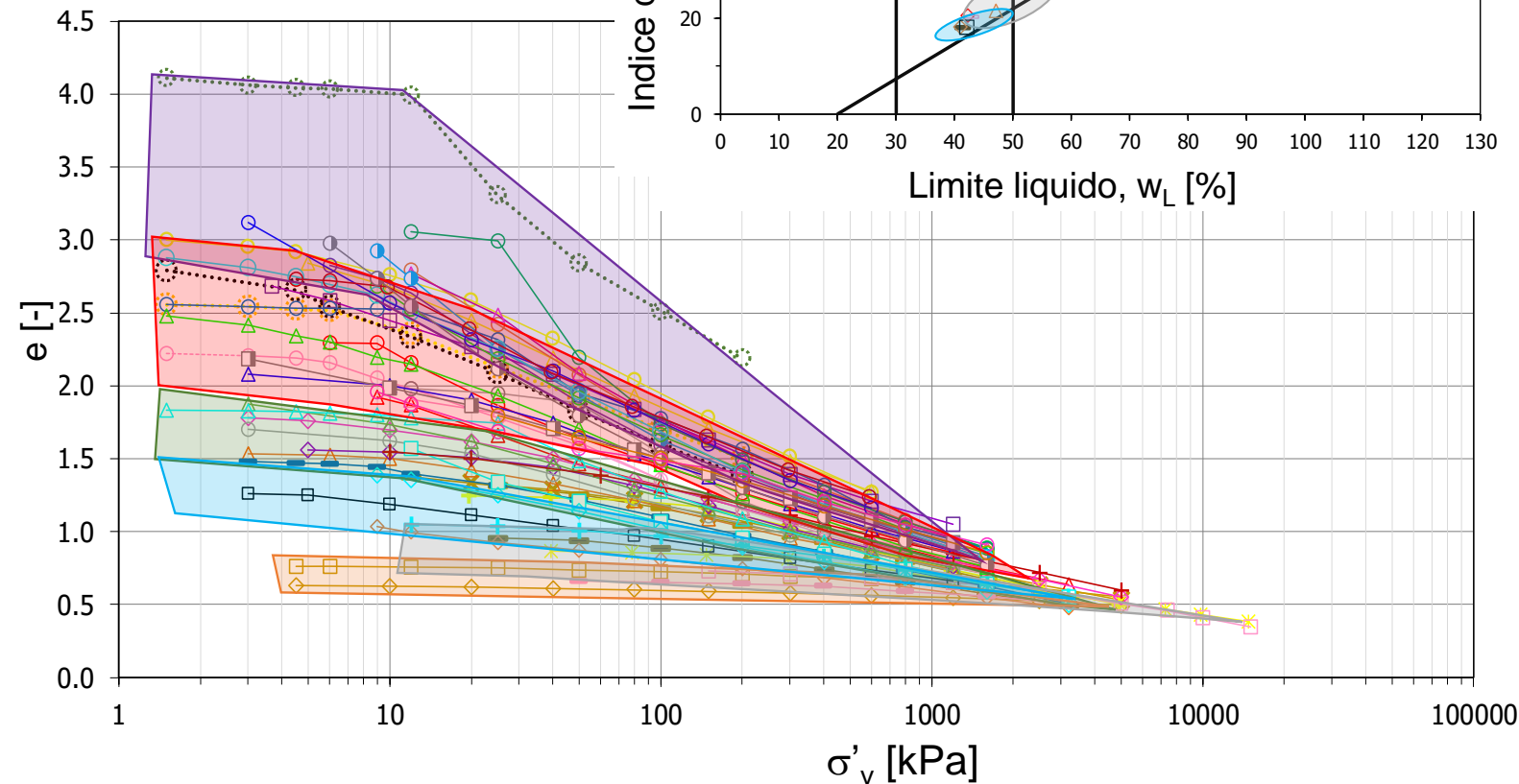
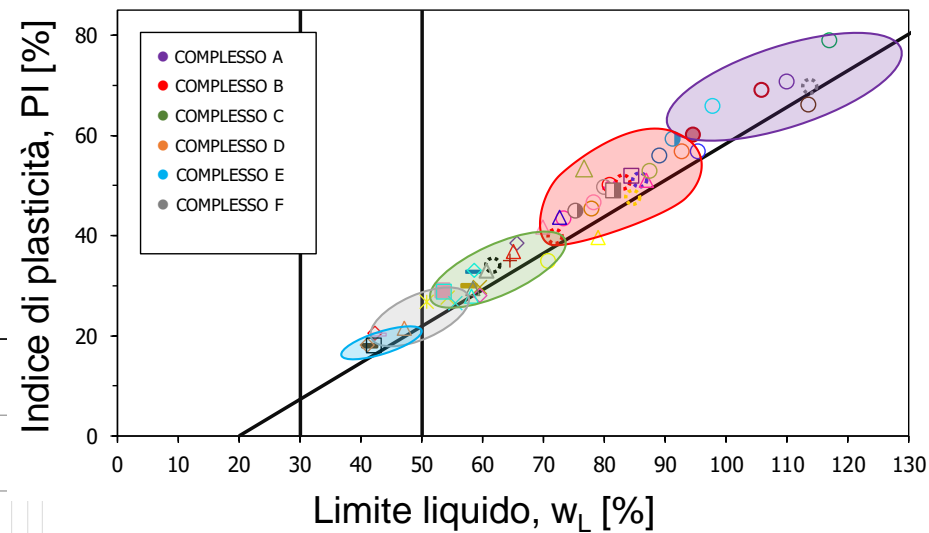


Cotecchia et al., 2021; open access: <https://www.nature.com/articles/s41598-021-82879-w/figures/11>



# CDSM: modello geo-idro-meccanico

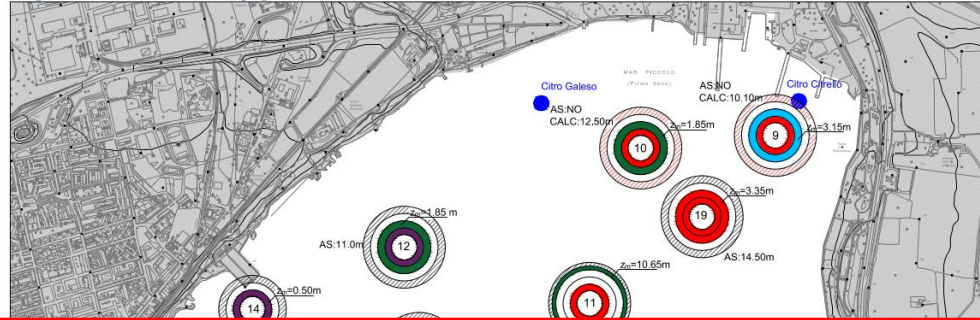
SUPERFLUIDO	A
FLUIDO	B
ARGILLE E LIMI PLASTICI	C
SABBIE	D
LIMI POCO PLASTICI	E
ARGILLE SUBAPPENNINE	F



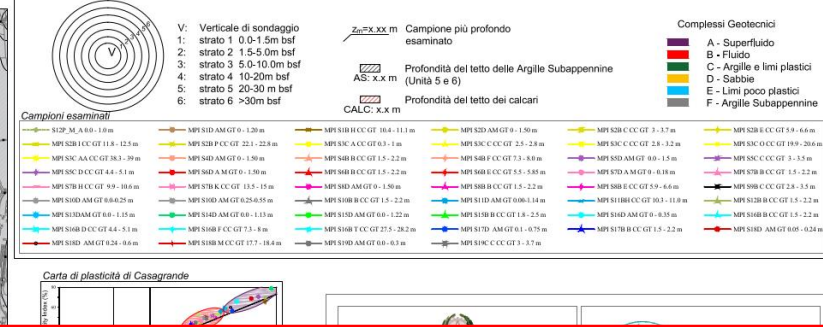
(Vitone et al., 2016; Sollecito, Vitone, Cotecchia 2019)



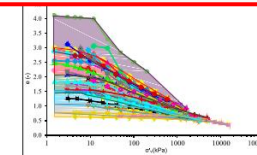
Allegato C3 - Modello Geo-meccanico di progetto



LEGENDA



z bsf		SF		MF		CF		w <sub>L</sub>		PI		LI		A		OM		c <sub>c</sub>		c <sub>s</sub>		k(e=1.5)		k(e <sub>0</sub> )		c <sub>k</sub>		c' <sub>p</sub>	φ' <sub>p</sub>	φ' <sub>cs</sub>		c <sub>u</sub>		D <sub>R</sub>	
m	m	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[-]	[-]	[%]	[%]	[-]	[-]	[-]	[-]	[m/s]	[m/s]	[m/s]	[m/s]	[-]	[-]	[kPa]	[°]	[°]	[°]	[kPa]	[kPa]	[%]	[%]
min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max			min	max	min	max	min	max
0.1	0.6	2.8	29.4	30.5	51.0	26.6	65.4	91.2	117.0	56.7	78.8	1.0	2.7	0.87	2.49	8.0	18.0	0.80	1.50	0.09	0.15	1E-11	8E-11			0.7	0.9	-	-	27.2	33.0	1.7	3.2	-	-
0.1	3.4	2.3	16.0	38.6	58.8	26.7	54.6	69.9	89.0	34.9	55.9	0.9	2.7	0.66	1.70	13.0	18.0	0.50	0.90	0.03	0.15	6E-11	7E-09			0.3	1.2	-	-	21.3	39.8	1.8	7.1	-	-
1.9	22.5	0.5	10.9	44.8	60.6	32.1	49.9	53.6	65.6	27.6	38.4	0.7	1.6	0.57	0.91	7.0	15.0	0.35	0.61	0.07	0.12	3E-10	3E-09			0.4	0.6	-	-	25.0	35.3	4.0	25.0	-	-
3.0	6.3	52.8	79.8	10.5	29.1	4.7	18.1	18.7	22.5	-	-	-	-	-	-	4.0	9.0	0.04	0.05	0.01	0.01	-	-	1E-07	1E-07	-	-	-	-	42.0	42.0	-	-	33.4	59.0
1.9	10.8	8.0	23.5	48.7	69.5	22.5	39.1	41.0	47.1	18.0	21.5	0.7	2.0	0.55	0.81	5.0	12.0	0.21	0.40	0.04	0.10	1E-09	7E-08			0.3	0.4	-	-	32.9	33.1	6.3	17.6	-	-
10.3	38.7	3.2	16.2	43.2	56.4	27.3	49.5	42.9	55.5	20.2	29.0	0.1	0.4	0.56	0.74	6.0	10.0	0.14	0.33	0.04	0.10	4E-09	2E-06			0.2	0.3	19.4	28.4	27.9	30.0	40.6	92.7	-	-



		z bsf		SF		MF		CF		w <sub>L</sub>		PI		U		A		OM		c <sub>c</sub>		c <sub>s</sub>		k(e=1.5)		k(e <sub>0</sub> )		c <sub>k</sub>		c' <sub>p</sub>		φ' <sub>p</sub>		φ' <sub>cs</sub>		c <sub>u</sub>		D <sub>R</sub>	
		m	max	m	max	m	max	m	max	m	max	m	max	m	max	m	max	m	max	m	max	m	max	m	max	m	max	m	max	m	max	m	max	m	max	m	max	m	max
		min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
SUPERFLUIDO	A	0.1	0.6	2.8	29.4	30.5	51.0	26.6	65.4	91.2	117.0	56.7	78.8	1.0	2.7	0.87	2.49	8.0	18.0	0.50	0.90	0.03	0.15	1E-11	8E-11			0.7	0.9	-	-	27.2	33.0	1.7	3.2	-	-		
FLUIDO	B	0.1	3.4	2.3	16.0	38.6	58.8	26.7	54.6	69.9	89.0	34.9	55.9	0.9	2.7	0.66	1.70	13.0	18.0	0.50	0.90	0.03	0.15	6E-11	7E-09			0.3	1.2	-	-	21.3	39.8	1.8	7.1	-	-		
ARGILLE E LIMI PLASTICI	C	1.9	22.5	0.5	10.9	44.8	60.6	32.1	49.9	53.6	65.6	27.6	38.4	0.7	1.6	0.57	0.91	7.0	15.0	0.35	0.61	0.07	0.12	3E-10	3E-09			0.4	0.6	-	-	25.0	35.3	4.0	25.0	-	-		
SABBIE	D	3.0	6.3	52.8	79.8	10.5	29.1	4.7	18.1	18.7	22.5	-	-	-	-	-	-	4.0	9.0	0.04	0.05	0.01	0.01	-	-	1E-07	1E-07	-	-	-	-	42.0	42.0	-	-	33.4	59.0		
LIMI POCO PLASTICI	E	1.9	10.8	8.0	23.5	48.7	69.5	22.5	39.1	41.0	47.1	18.0	21.5	0.7	2.0	0.55	0.81	5.0	12.0	0.21	0.40	0.04	0.10	1E-09	7E-08			0.3	0.4	-	-	32.9	33.1	6.3	17.6	-	-		
ARGILLE SUBAPPENNINE	F	10.3	38.7	3.2	16.2	43.2	56.4	27.3	49.5	42.9	55.5	20.2	29.0	0.1	0.4	0.56	0.74	6.0	10.0	0.14	0.33	0.04	0.10	4E-09	2E-06			0.2	0.3	19.4	28.4	27.9	30.0	40.6	92.7	-	-		

**I SENO DEL MAR PICCOLO - TARANTO**

**Allegato C3**  
**MODELLO GEO-MECCANICO DI PROGETTO**

Programma tecnico-economico-operativo-temporale

UNITÀ A: GEOTECNICA

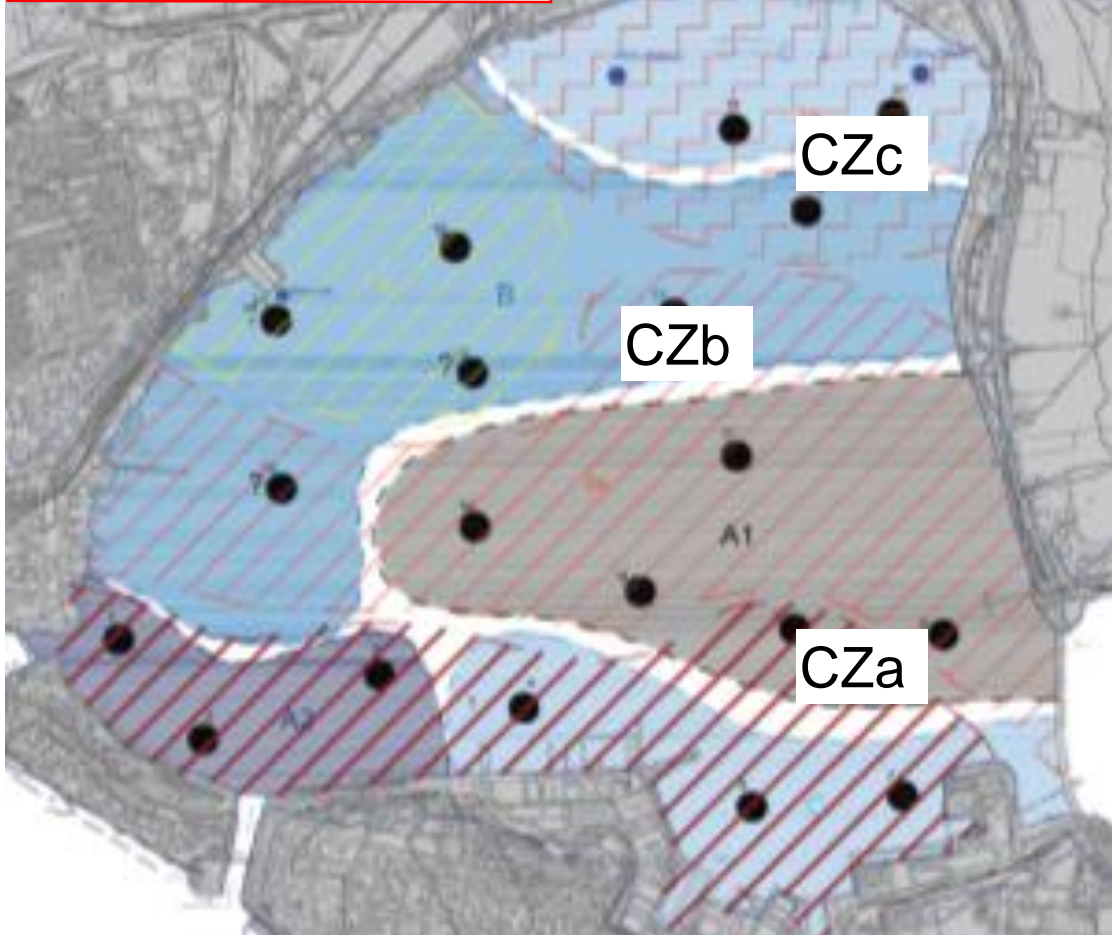
Responsabile scientifico PTEOT  
UNITÀ A - GEOTECNICA  
FEDERICA COTECCHIA

Politecnico di Bari  
Il Responsabile Scientifico dell'Accordo  
Magnifico Rettore

Nome file: Allegato C3 - Modello Geo-meccanico di progetto.pdf

Data: 10/06/2017



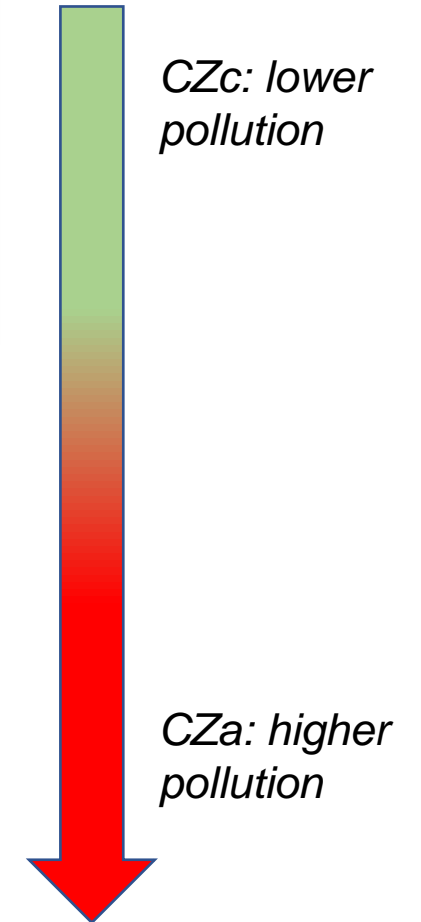


**LEGENDA ZONAZIONE CHIMO-MECCANICA**  
Del COMMISSARIO STRAORDINARIO 30/6/2017

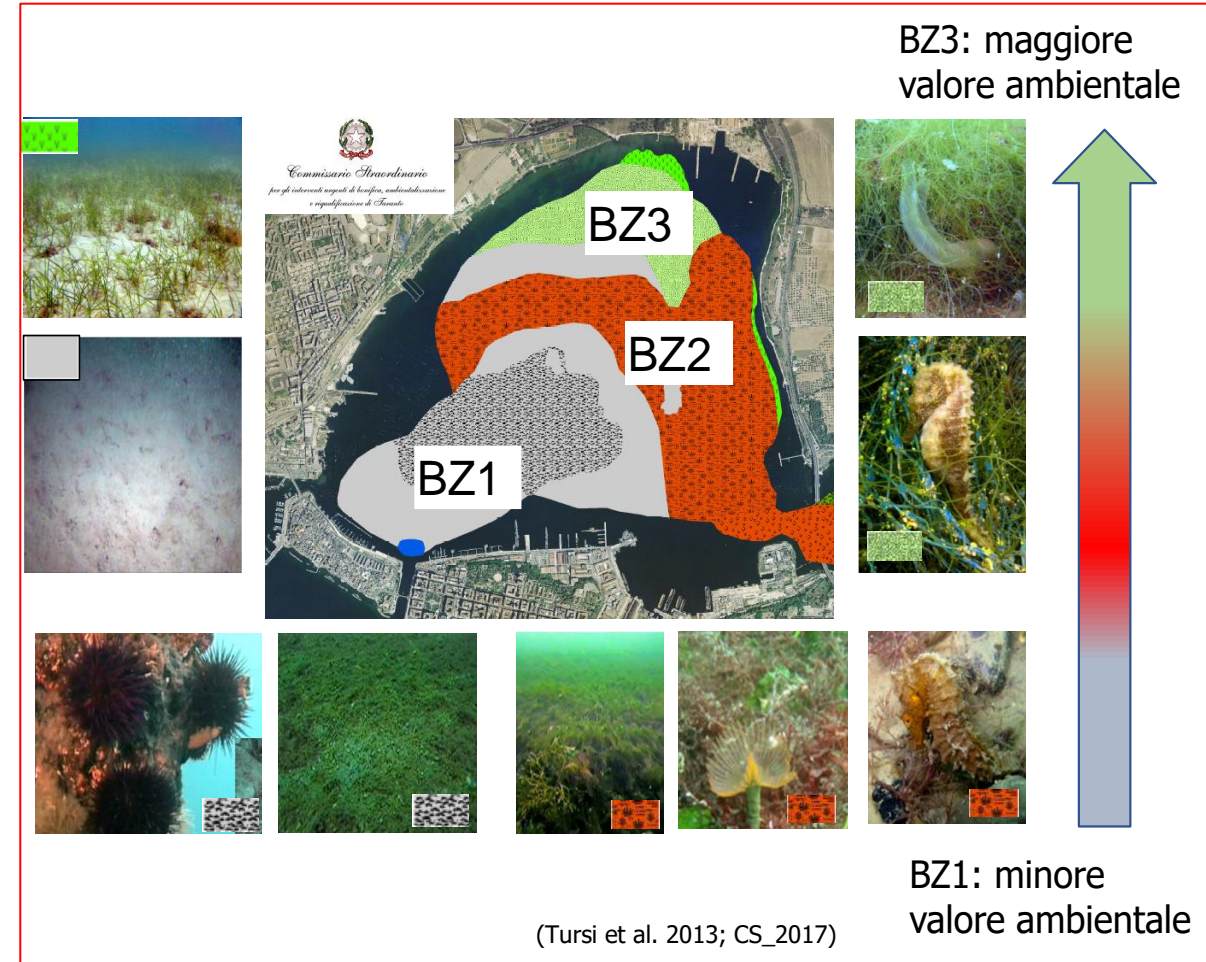
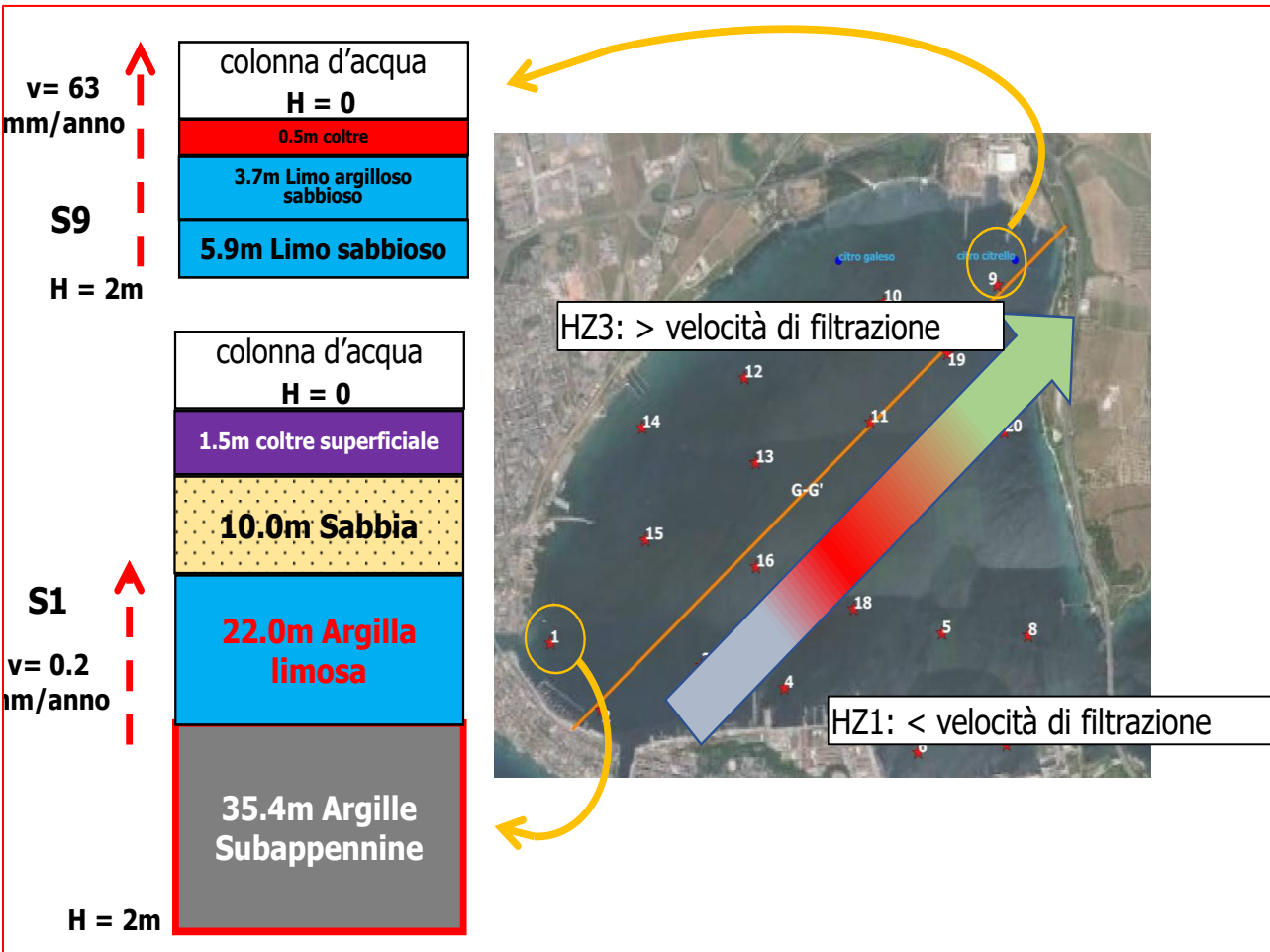
<p><b>A1</b> - Estratto geomeccanico A1 (P1A1)</p> <p>0-0.5 m dal fondo: presenza del complesso di compressione (complesso A1)</p> <p>→ Estratto geomeccanico sedimenti (dalla complessione A1)</p>	<p><b>B1</b> - Estratto geomeccanico B1 (P1B1)</p> <p>0-1.0 m dal fondo: presenza del complesso di compressione (complesso B1)</p> <p>→ Estratto geomeccanico sedimenti (dalla complessione B1)</p>
<p><b>A2</b> - Estratto geomeccanico A2 (P1A2)</p> <p>0-0.5 m dal fondo: presenza del complesso di compressione (complesso A2)</p> <p>→ Estratto geomeccanico sedimenti (dalla complessione A2)</p>	<p><b>B2</b> - Estratto geomeccanico B2 (P1B2)</p> <p>0-1.0 m dal fondo: presenza del complesso di compressione (complesso B2)</p> <p>→ Estratto geomeccanico sedimenti (dalla complessione B2)</p>

**LEGENDA ZONAZIONE CHIMICA**  
Del COMMISSARIO STRAORDINARIO 30/6/2017

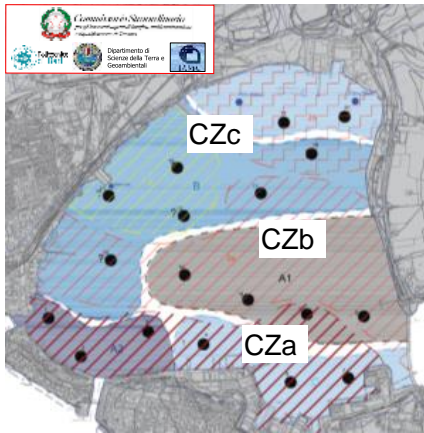
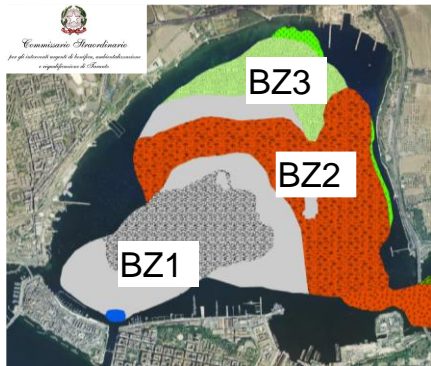
<p><b>Zona 1</b> - Presenza di...</p> <p>Indicatore di presenza della coppia "quartz" in superficie...</p>	<p><b>Zona 2</b> - Presenza di...</p> <p>Indicatore di presenza della coppia "quartz" in superficie...</p>
<p><b>Zona 3</b> - Presenza di...</p> <p>Indicatore di presenza della coppia "quartz" in superficie...</p>	<p><b>Zona 4</b> - Presenza di...</p> <p>Indicatore di presenza della coppia "quartz" in superficie...</p>





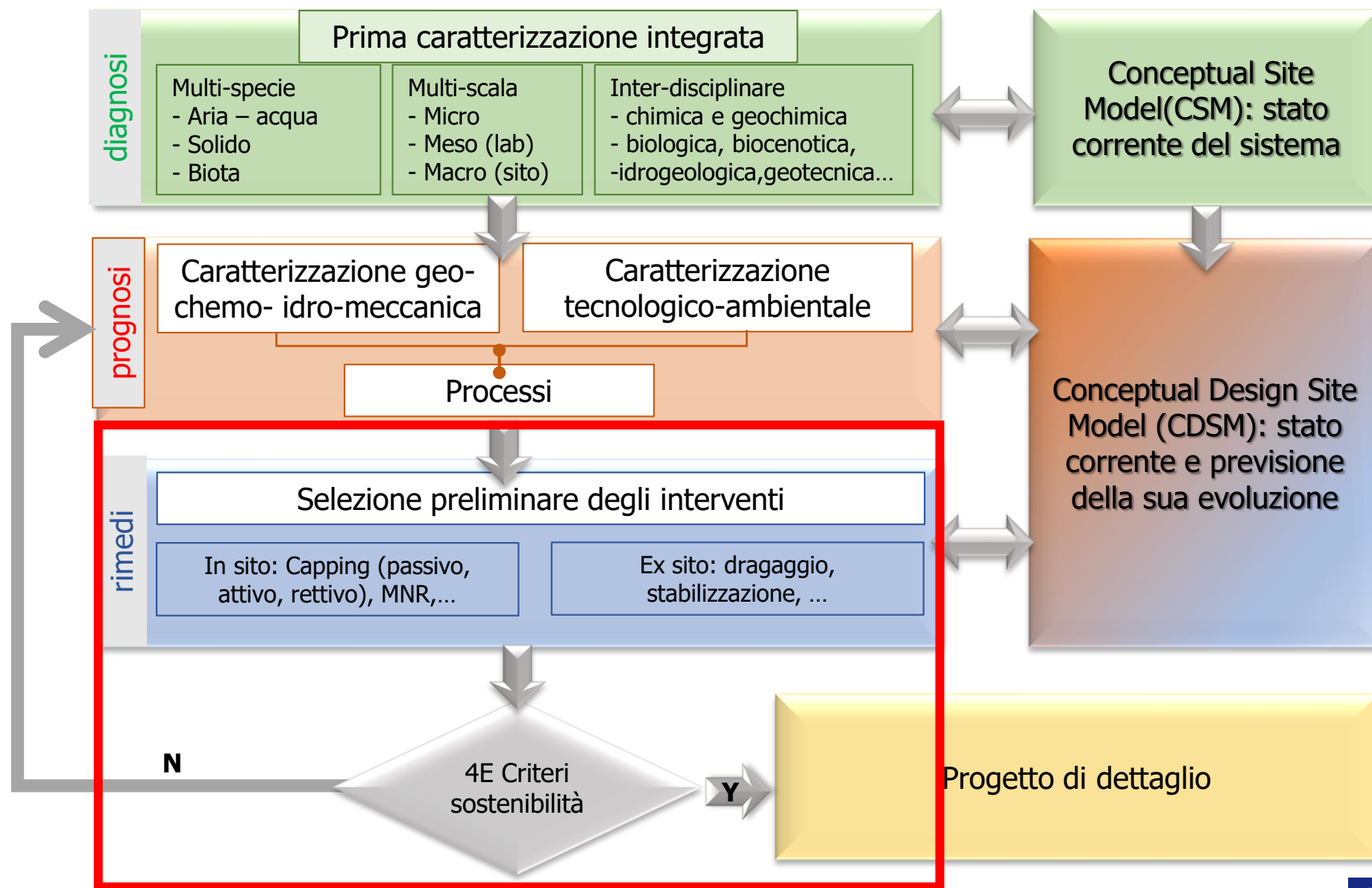






		ENGINEERING (GEOTECHNICAL AND HYDRAULIC ZONES)								
		GZ-HZany	GZany -HZ1-2	GZany -HZ 3	GZ1-2 -HZany	GZ3-4 -HZany	GZ3 -HZ1-2	GZ3 -HZ3	GZ4 -HZ1-2	GZ4 -HZ3
ENVIRONMENT (CHEMICAL AND BIOCEONONIS ZONES)	CZa - BZ1	1	1	1	1	1	1	1	1	1
	CZa - BZ2	-	1	1-2	-	-	-	-	-	-
	CZa - BZ3	1-2-3	1-2-3	1-2-3	1-2-3	1-2-3	1-2-3	1-2-3	1-2-3	1-2-3
	CZb - BZ1	-	-	-	1-2	2	-	-	-	-
	CZb - BZ2	-	-	-	1-2	-	2	2-3	2	2-3
	CZb - BZ3	-	-	-	1-2-3	-	2-3	3	2-3	3
	CZc - BZany	3	3	3	3	3	3	3	3	3

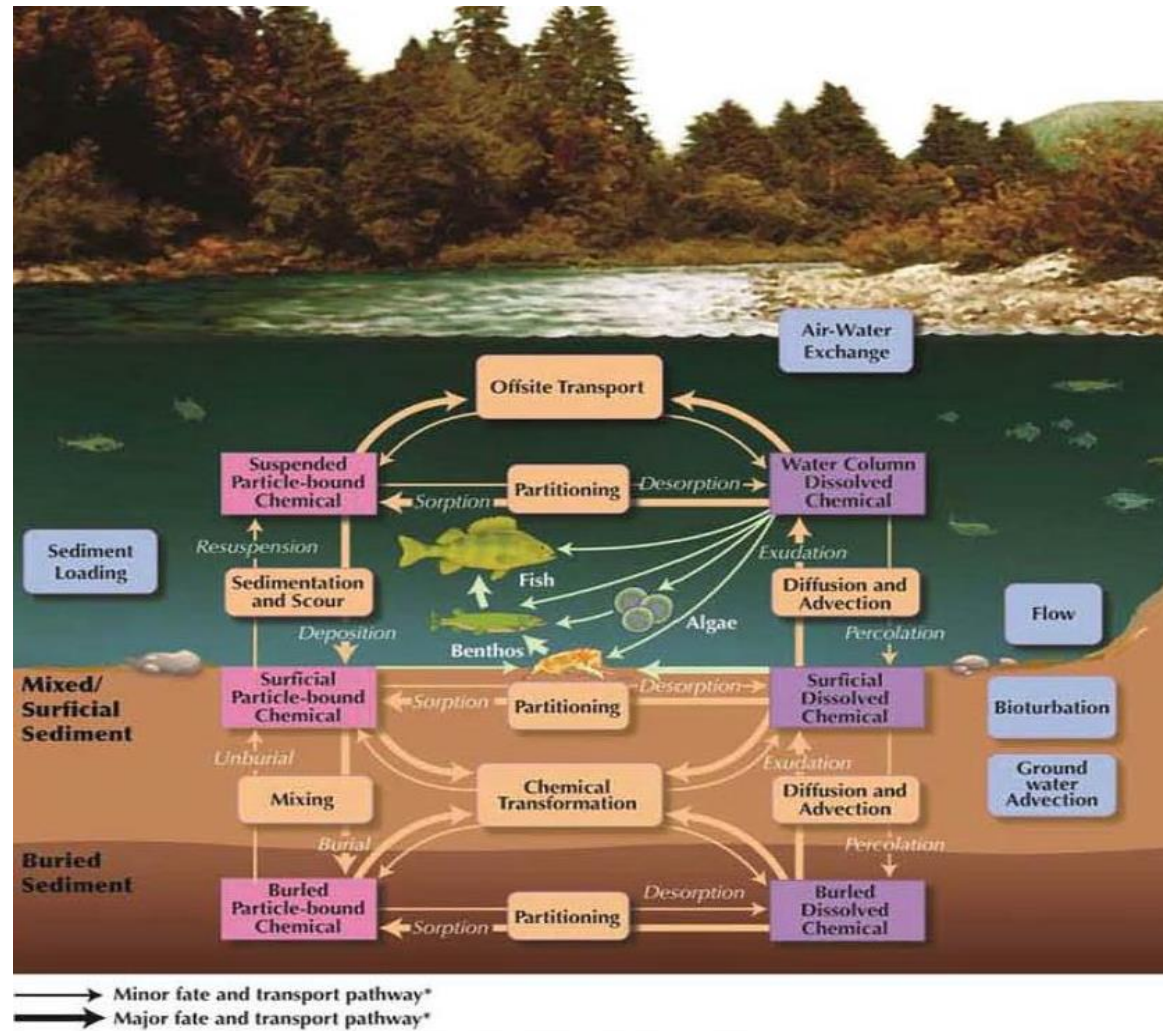
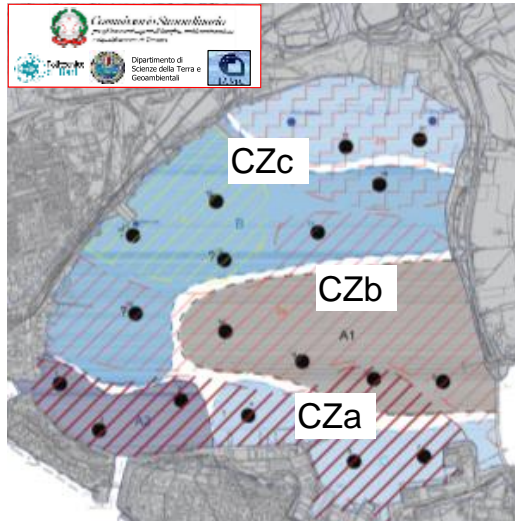






## Recupero Naturale Monitorato

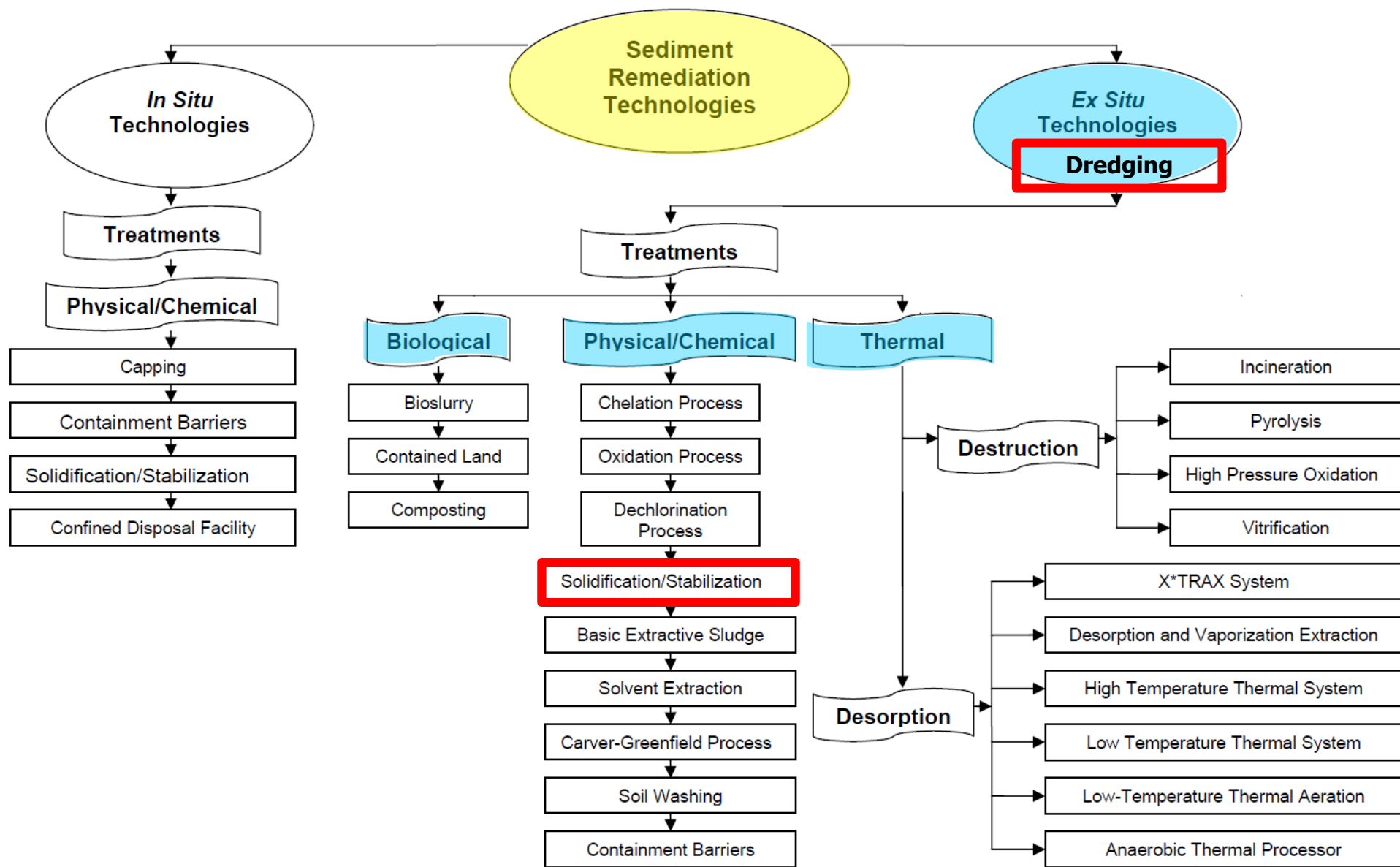
*Si tratta di un intervento a tutti gli effetti e consiste nel monitorare il sistema e la sua evoluzione e quella di tutti i numerosi processi in atto.*



(Reible, 2014)



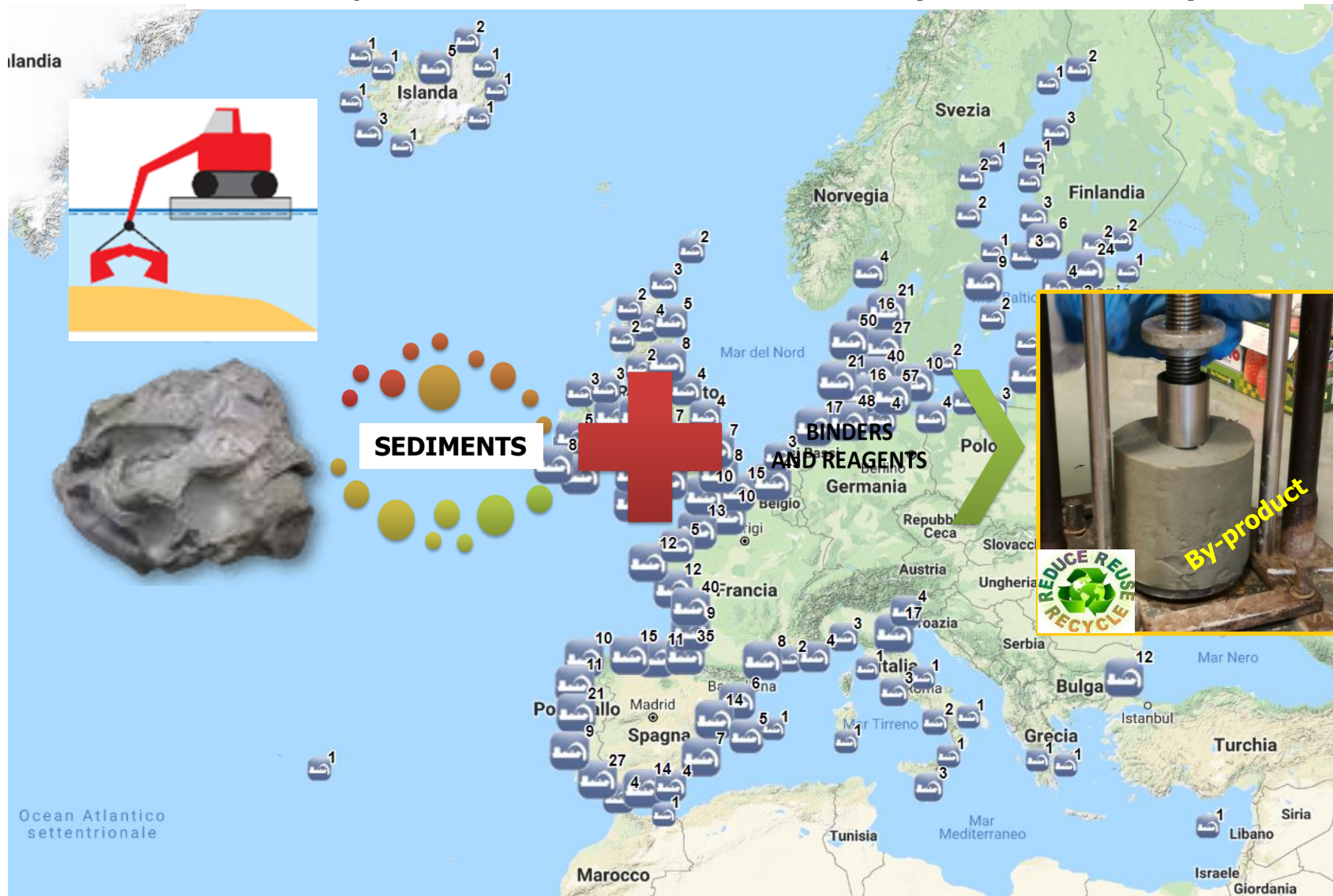
# aree a basso grado di resilienza (1-2): soluzioni tecnologiche



(ICS UNIDO, 2007)



In Europa che 200 milioni m<sup>3</sup>/anno (SedNet 2011) di sedimenti







## Sedimenti



Borsa PON RI XXXIII ciclo, Rossella Petti 2018-2021

## Leganti



**Italcementi**  
HEIDELBERGCEMENT Group

**Scheda tecnica**  
**i.pro TERMOCEM GREEN 42,5 N**  
CEM III/A 42,5 N

**Descrizione**  
i.pro TERMOCEM GREEN 42,5 N è un cemento di altoforno con un contenuto di materiale di riciclo pre-consumo superiore al 30 % ed è prodotto con emissioni di CO<sub>2</sub> (Core Processes) inferiori a 550 kg/t contro un dato di oltre 750 kg/t per un CEM I.



**Italcementi**  
HEIDELBERGCEMENT Group

**Scheda tecnica**  
**i.tech ALI CEM GREEN**

**Descrizione**  
i.tech ALI CEM GREEN è una miscela di clinker solfoalluminoso (i.tech ALI PRE GREEN) e solfato di calcio micronizzato dosato in percentuale stechiometrica sul clinker, con un contenuto di materiale di riciclo pre-consumo del 40% ed è prodotto con emissioni di CO<sub>2</sub> (Core Processes) pari a 400 kg/t contro un dato di oltre 750 kg/t per un CEM I. i.tech ALI CEM GREEN permette di ottenere formulazioni il cui tempo di presa può essere agevolmente regolato variando il rapporto di miscela con il cemento Portland.

## Mitili







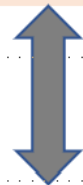
## Approach and strategy

ETH Zürich

11

Multiscale **geo-chemo-hydro-mechanical** analyses

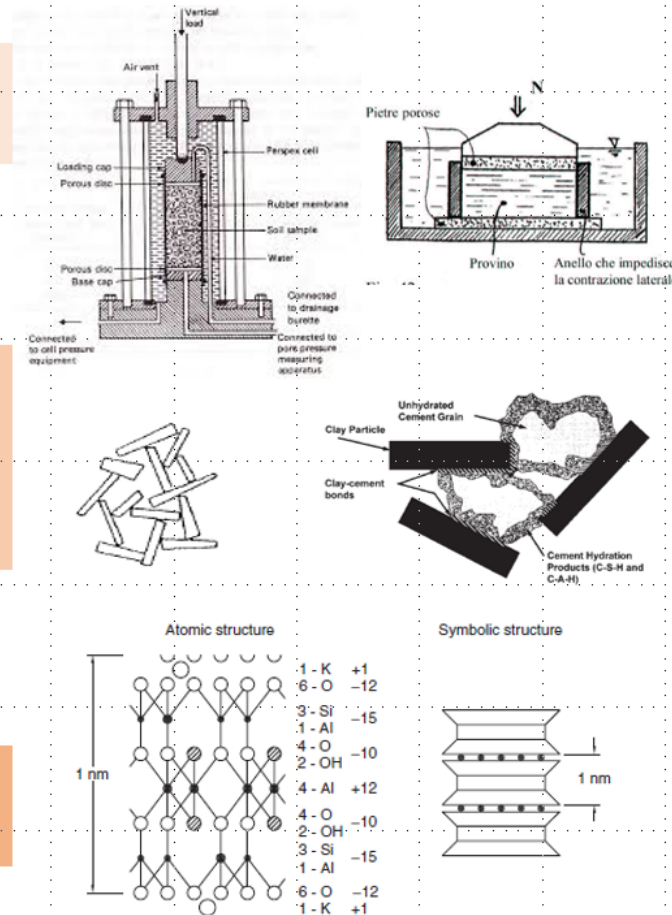
MESO-SCALE (LAB)  
BEHAVIOUR



MICRO-SCALE:  
PARTICLES  
ARRANGEMENT AND  
AGGREGATION



MICRO TO NANO-SCALE:  
PARTICLE LEVEL

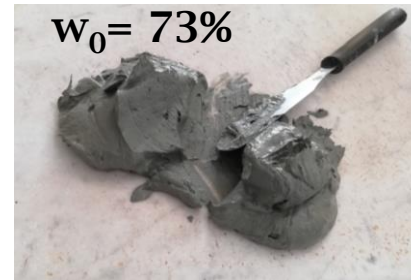


- Physical properties
- UCT
- 1-D compression test
- Triaxial test
- Texturometer
- Leaching test, etc....

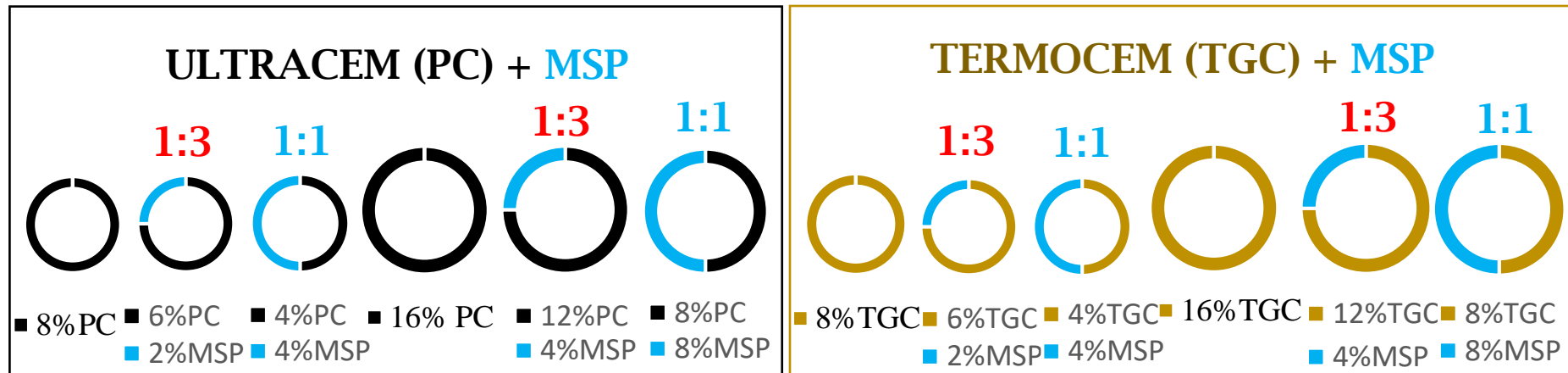
- Scanning Electron Microscopy (SEM)
- Mercury Intrusion Porosimetry (MIP)
- ...

- X-Ray diffraction (XRD)
- FT-IR
- ...

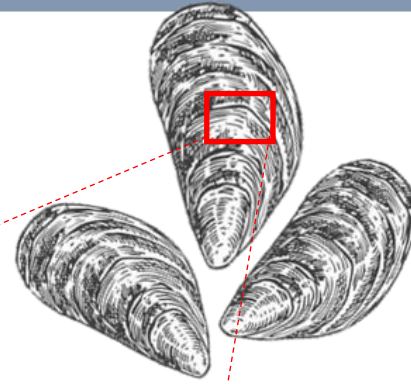




+



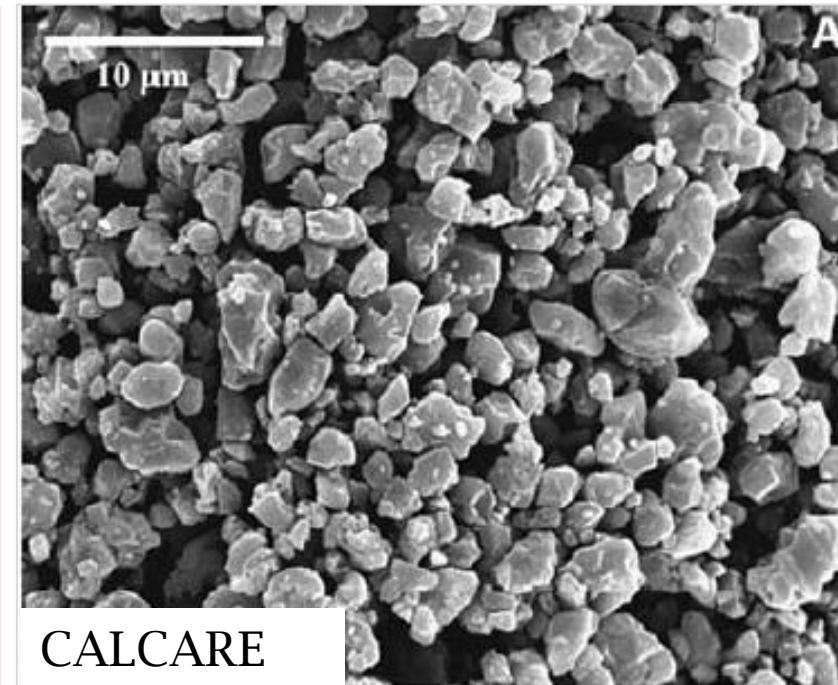




**Composizione chimica:**  
Principalmente ossido di calcio,  
uno dei principali componenti del  
cemento.



GUSCI DI MITILI



CALCARE



# preparazione della polvere di gusci di mitili

Lavaggio



Trattamento  
termico  
(105°C per 48h)



Macinazione

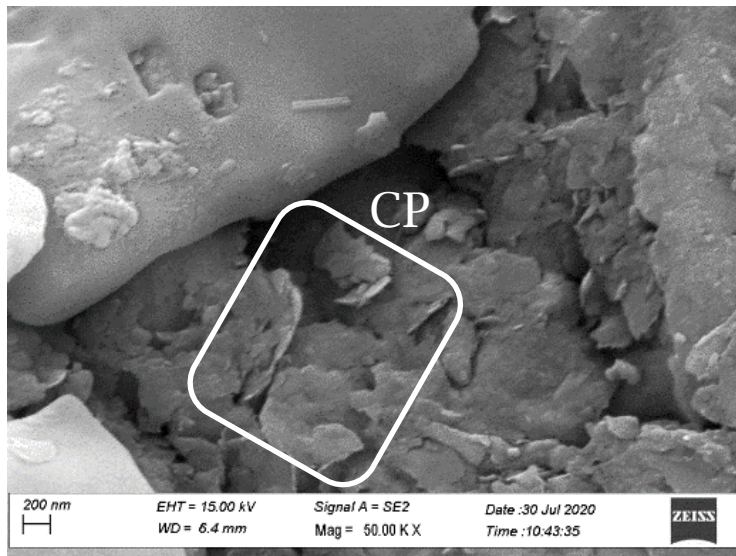
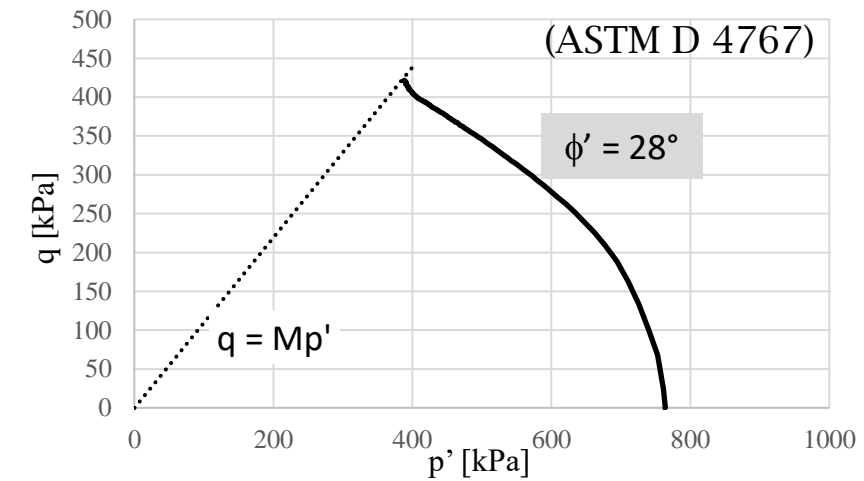
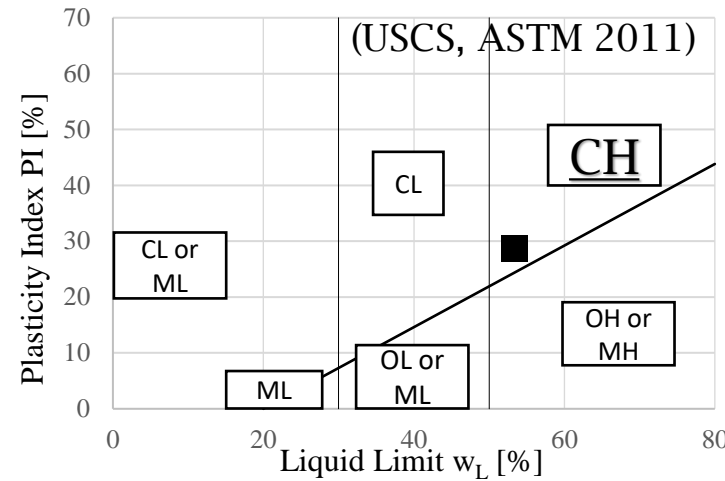
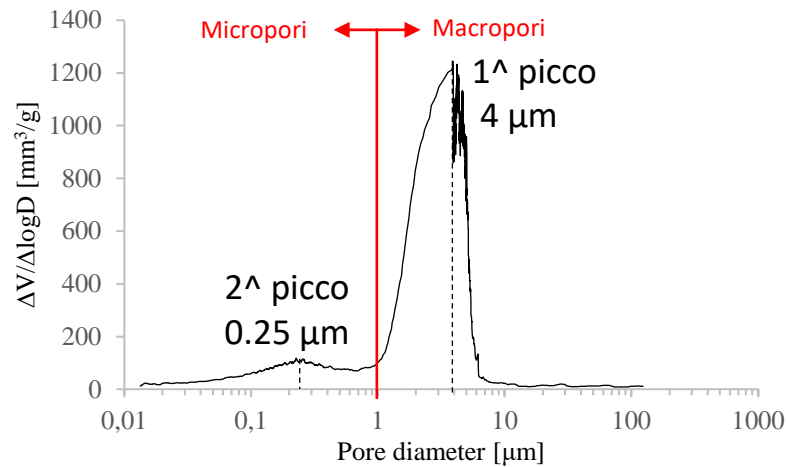


Setacciatura

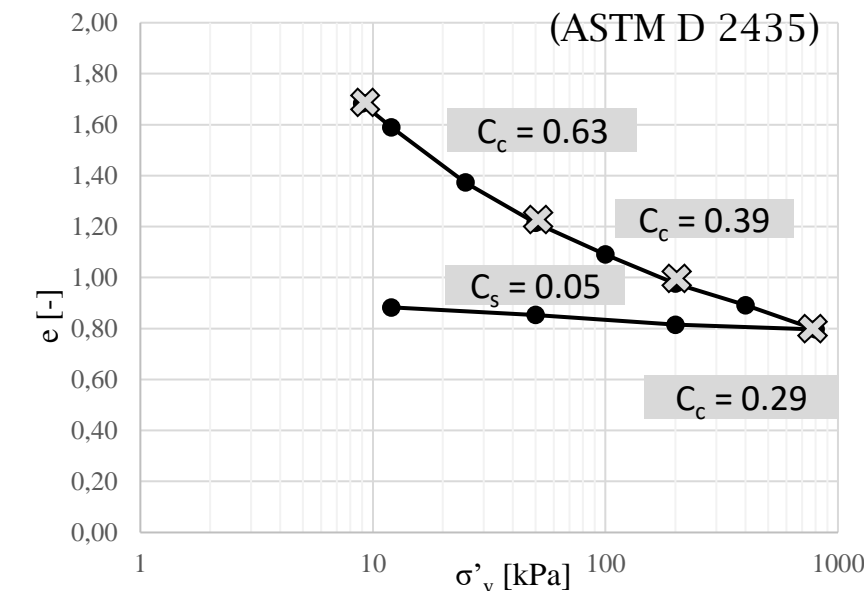
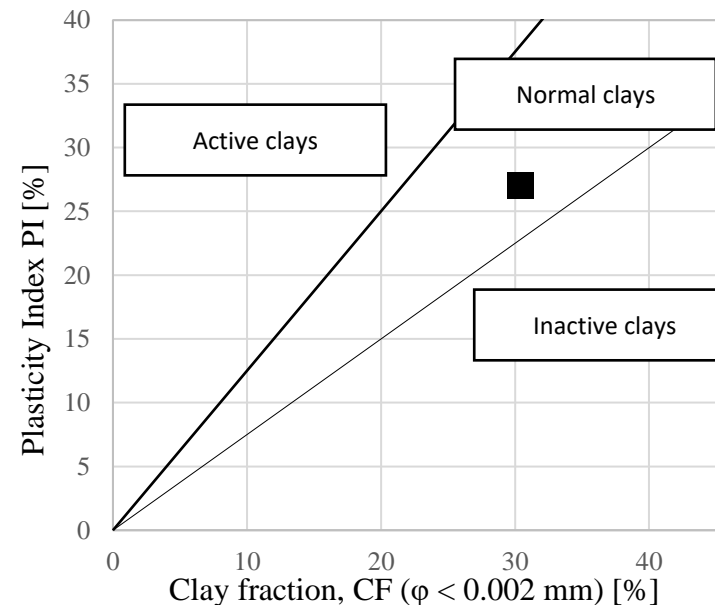




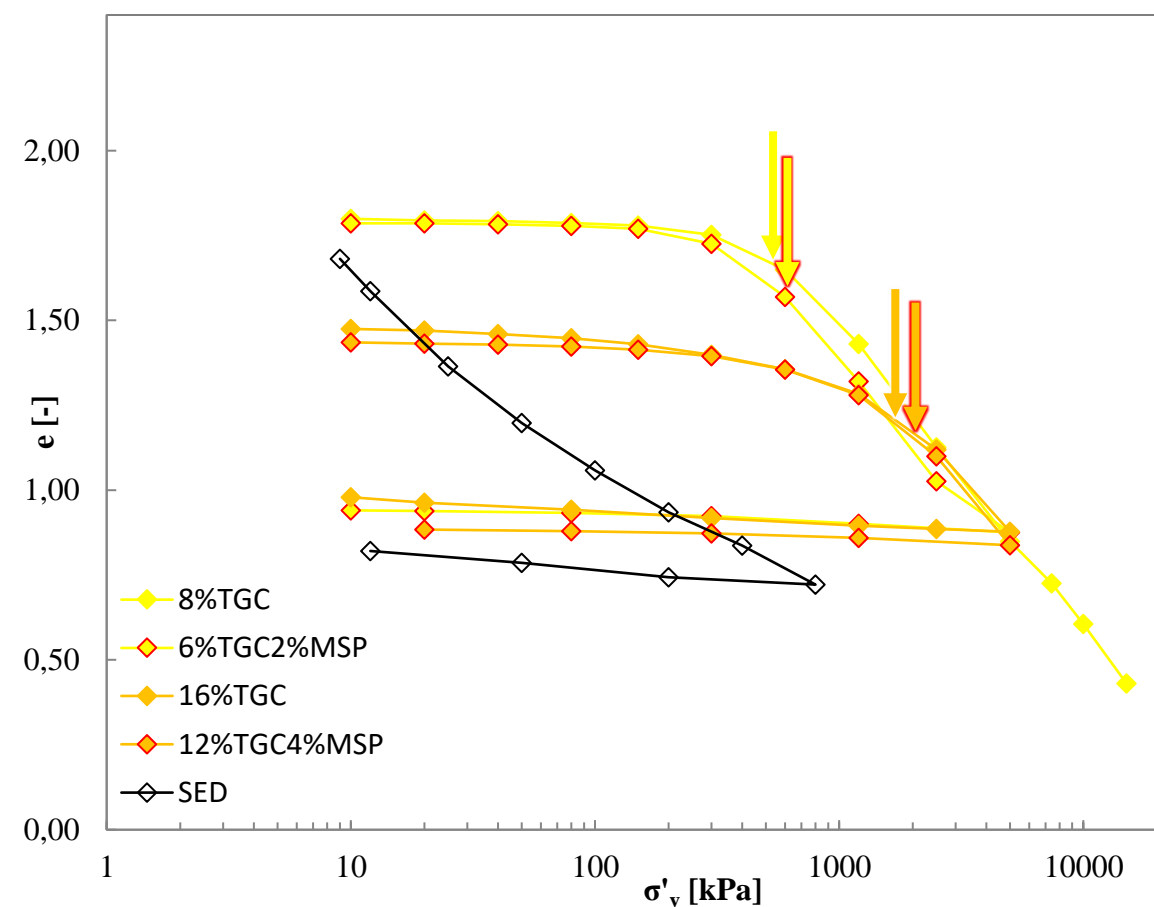
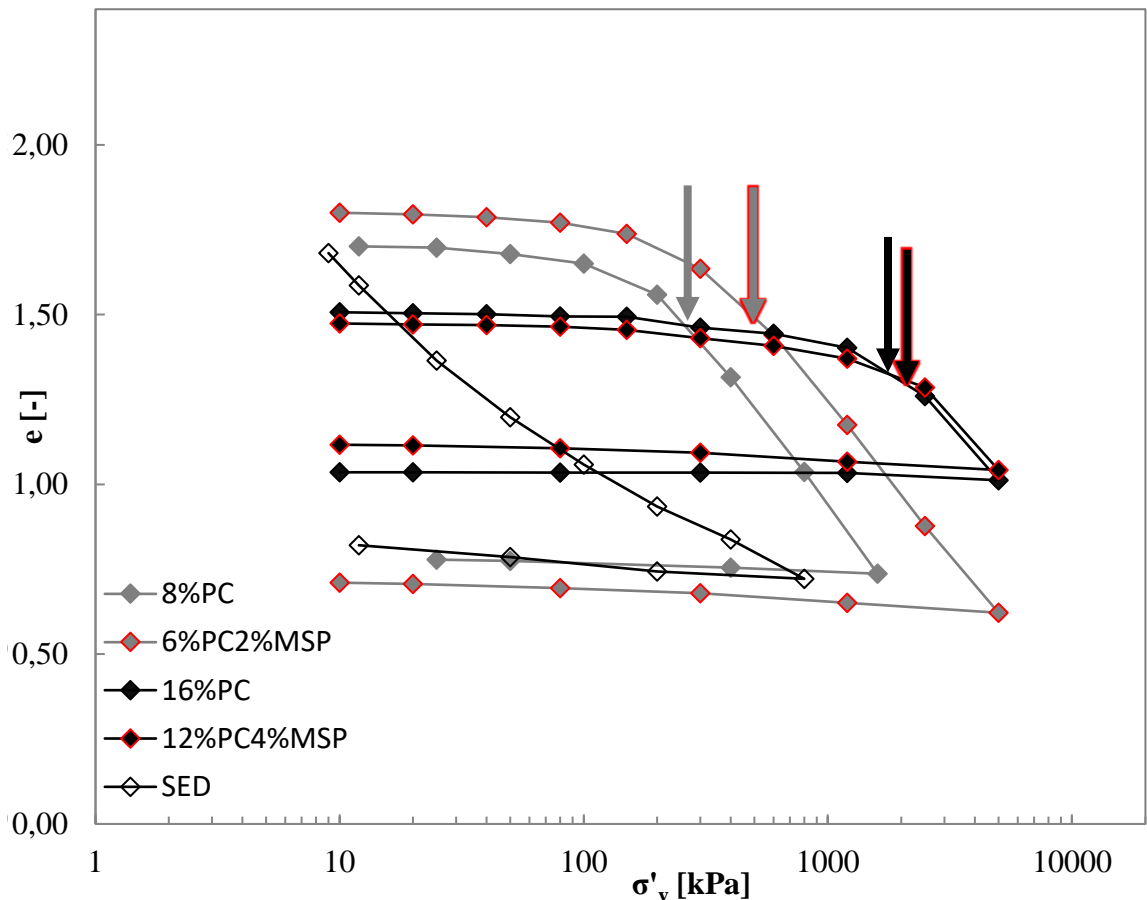
# alcuni risultati: caratterizzazione del sedimento naturale



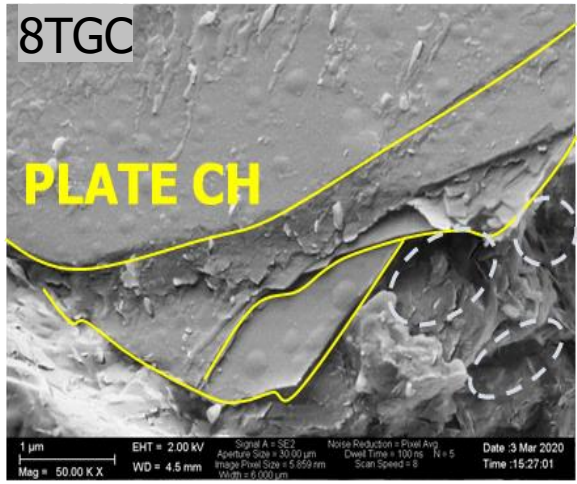
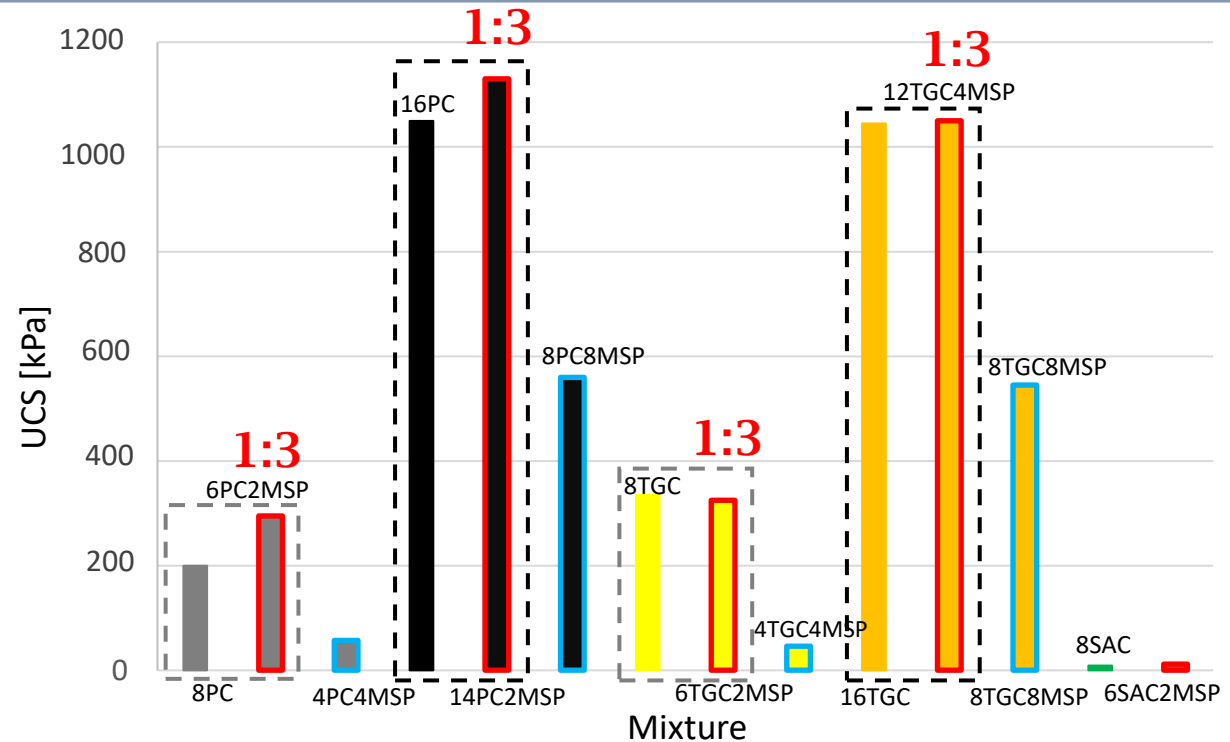
CP: particelle argillose











Mixture	8PC-8TGC	6TGC2MSP	6PC2MSP
CEC [meq/100g]	7	10.4	10.1





## Call: LIFE-2021-SAP-ENV

(Circular Economy and Quality of Life - Standard Action Projects (SAP))

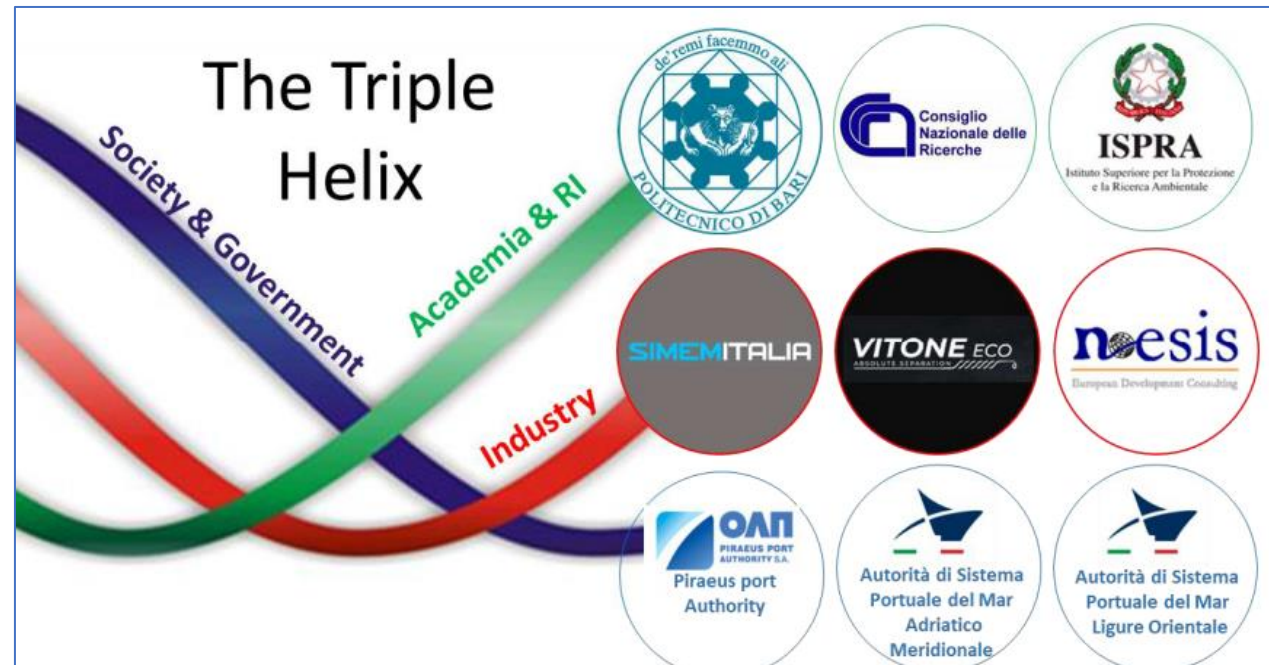
## Topic: LIFE-2021-SAP-ENV-ENVIRONMENT

Type of Action: LIFE-PJG

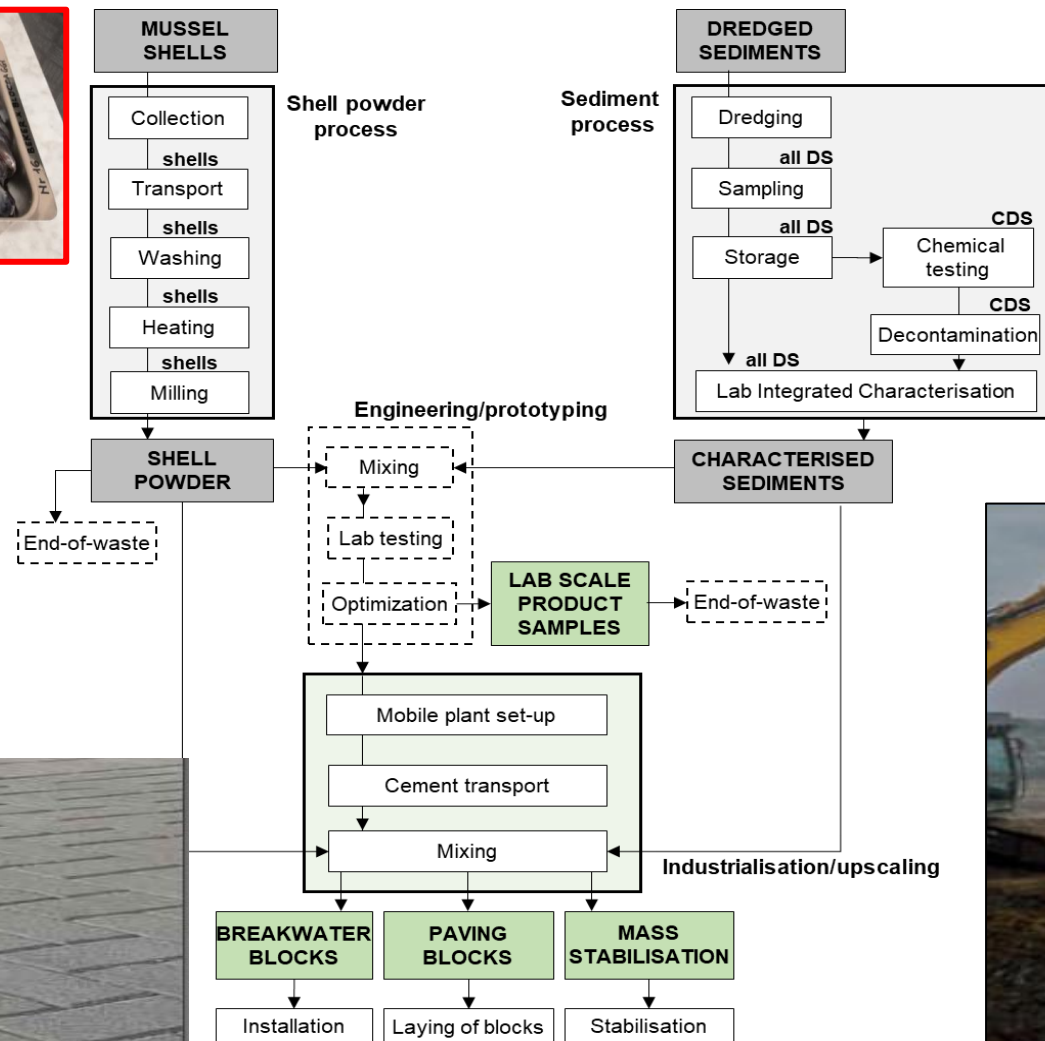


Proposal number: 101074413

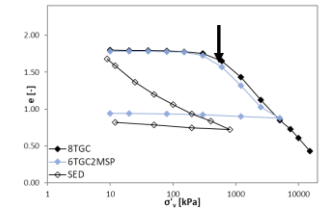
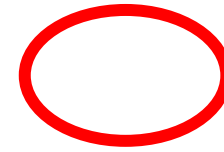
Proposal acronym: GREENLIFE4SEAS







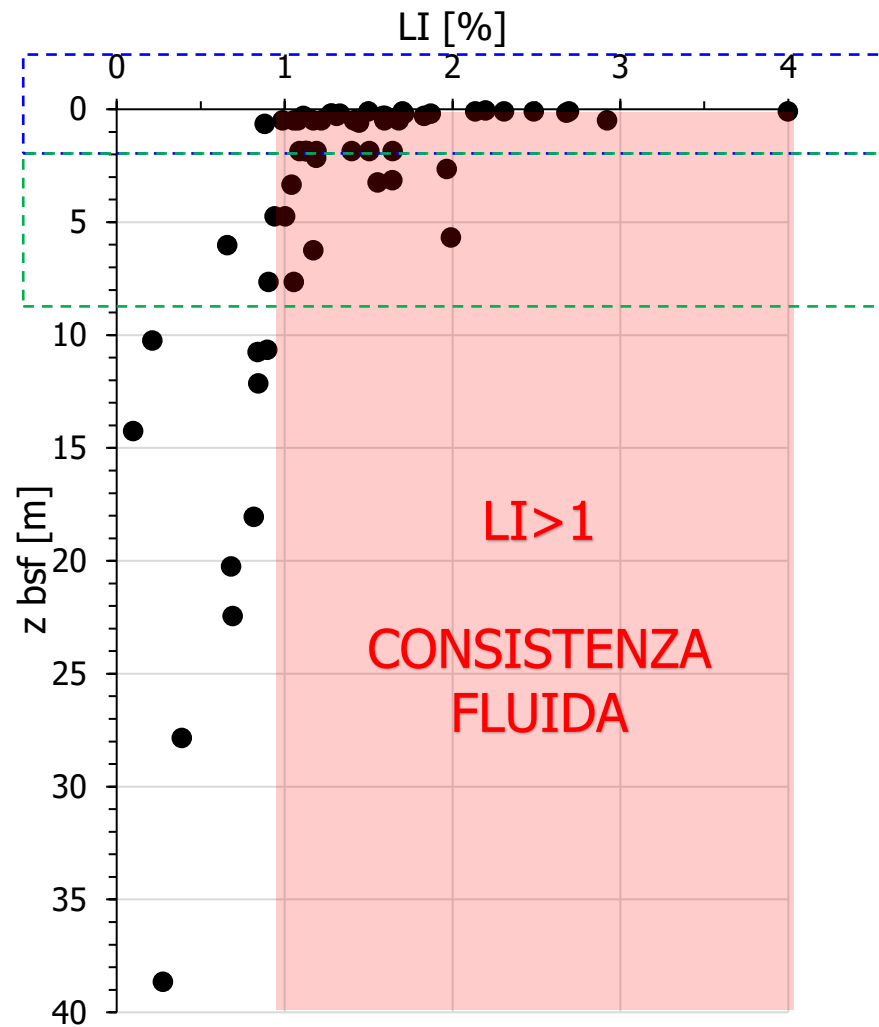






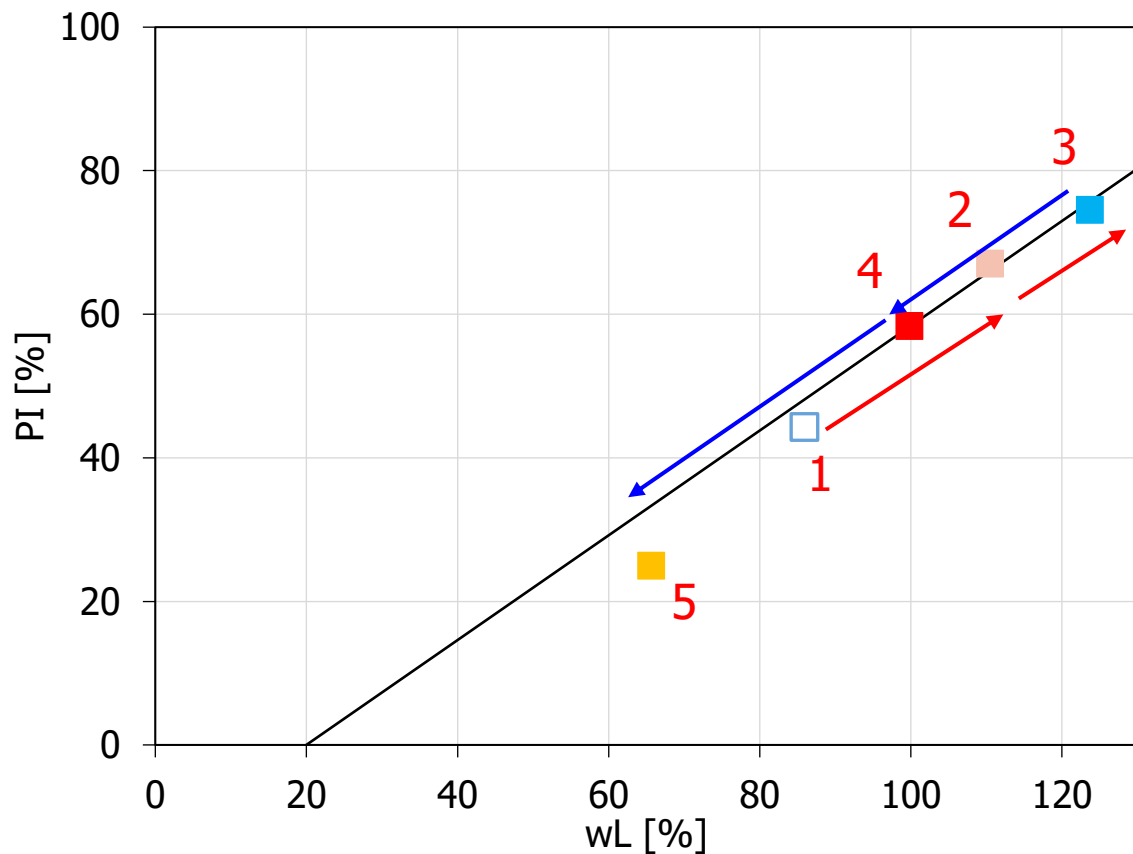






(Vitone et al., 2016; Sollecito et al., 2019)

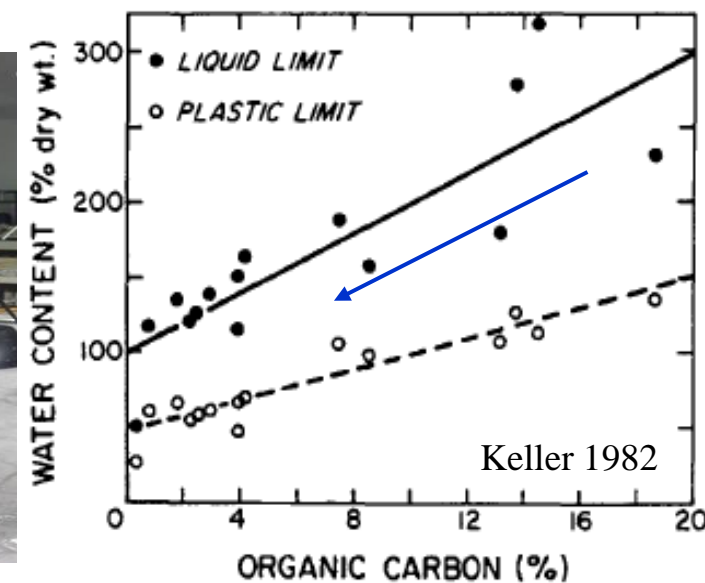




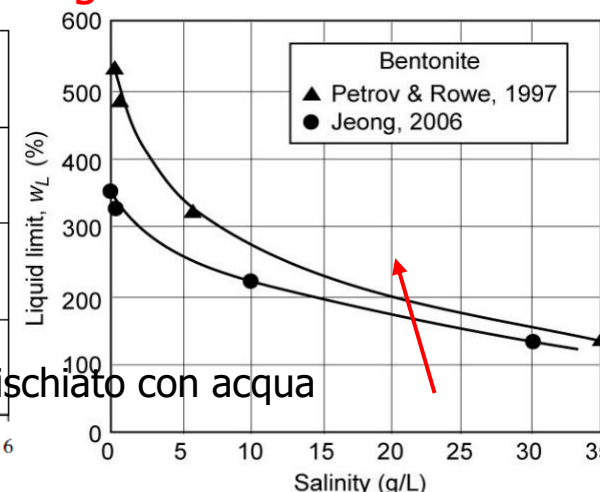
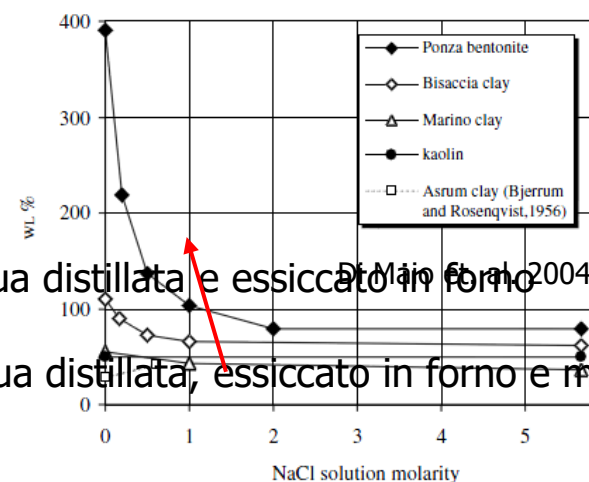
	Hg	
	mg/kg	m
S3M (1m bsf)	38.36	



## SEI STEP DI LAVAGGIO



## Mineralogie active



□ Determinazioni 2014

■ Determinazioni 2016

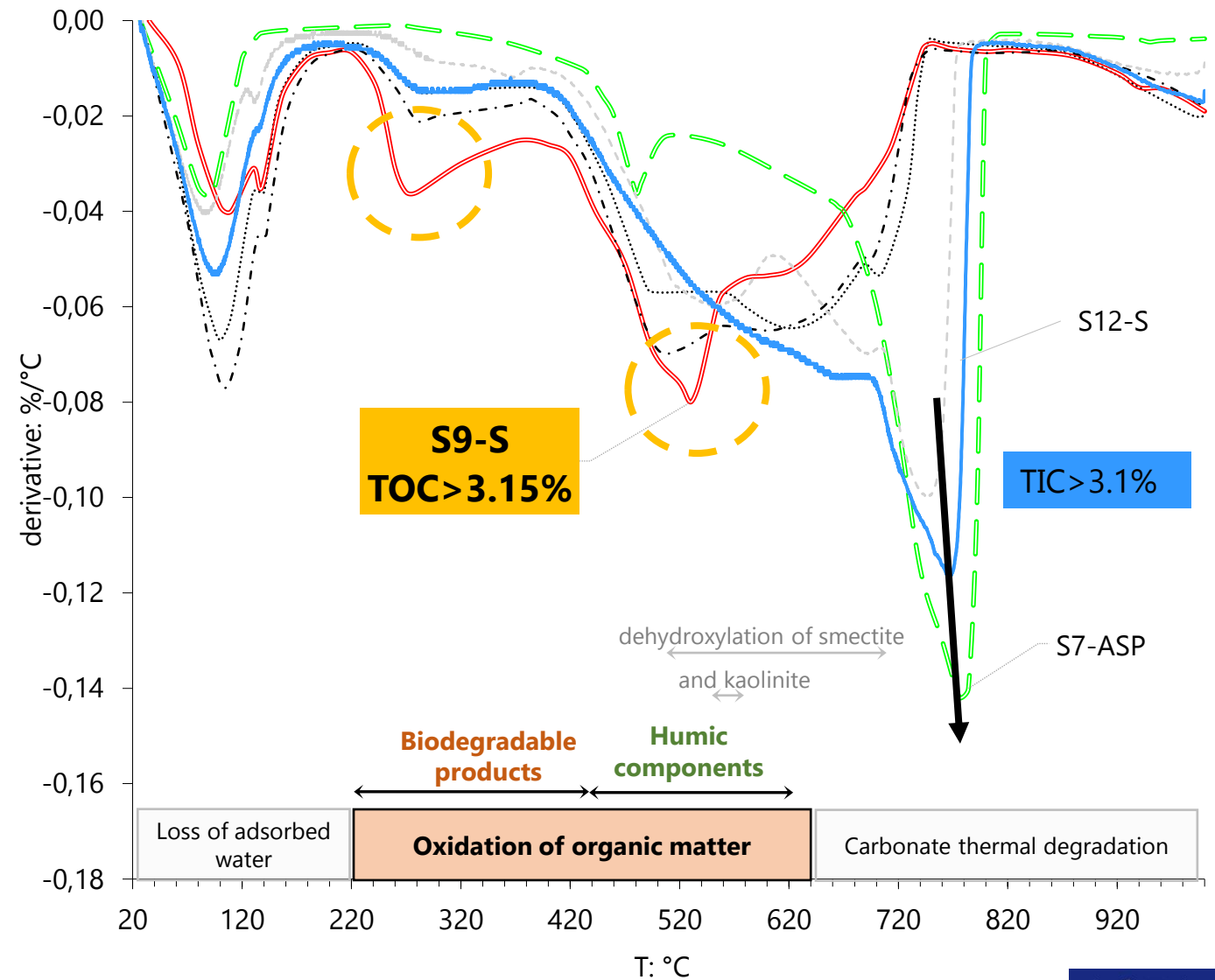
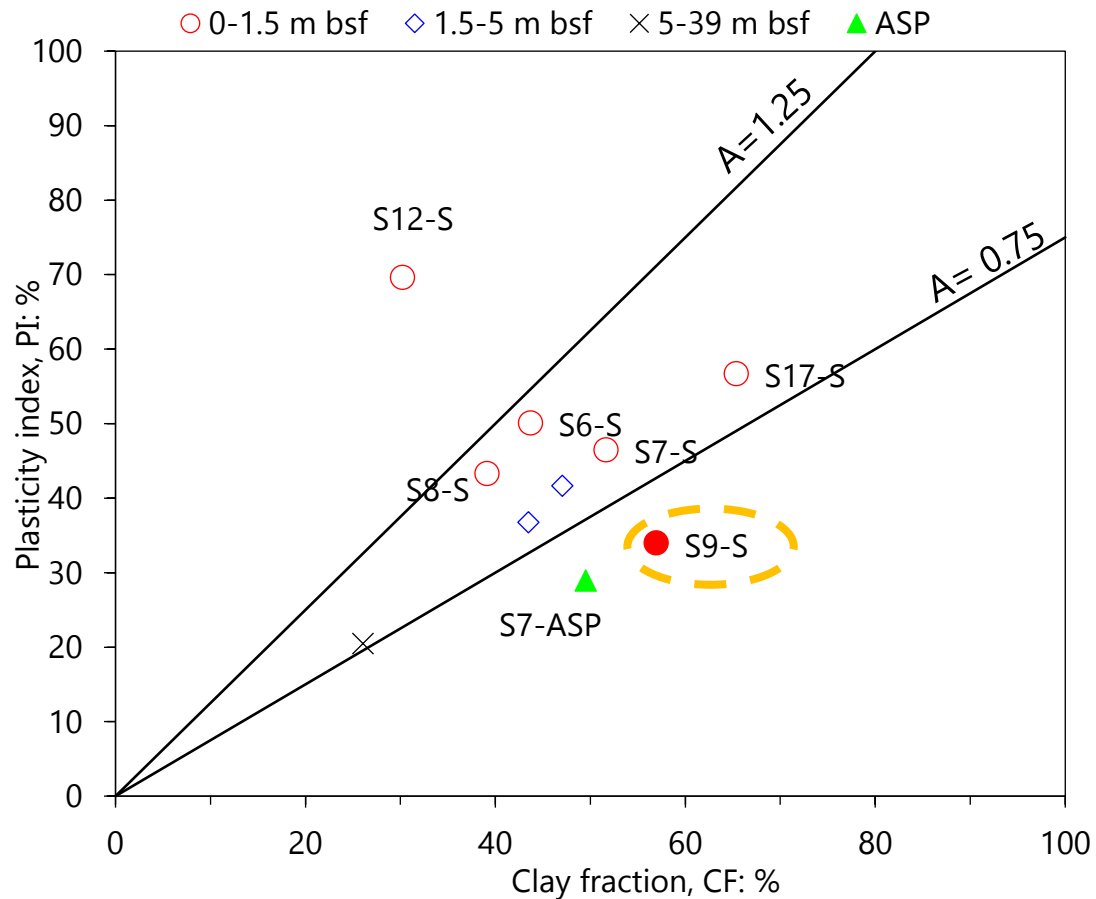
■ Lavato con acqua distillata

■ Lavato con acqua distillata e essiccato in forno

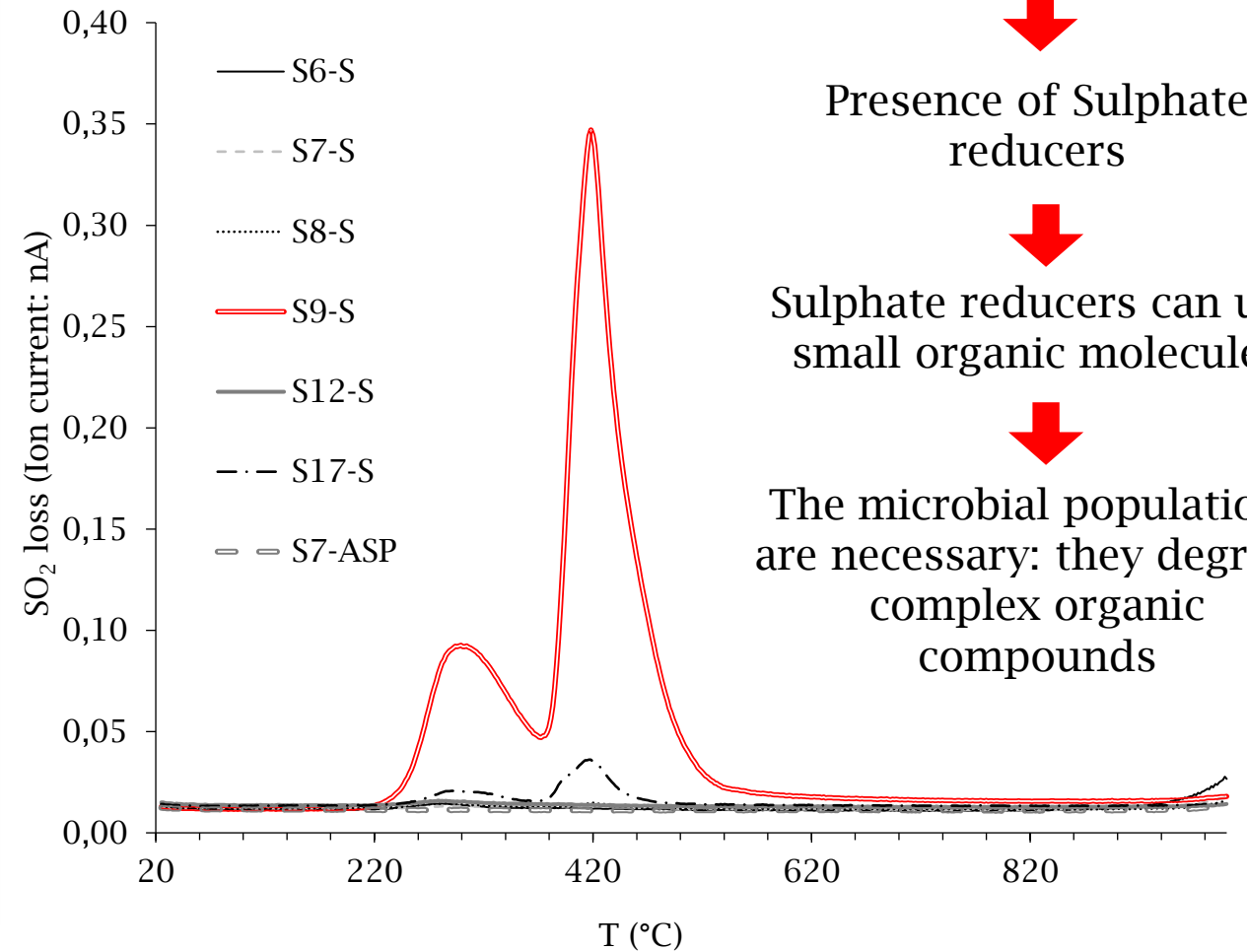
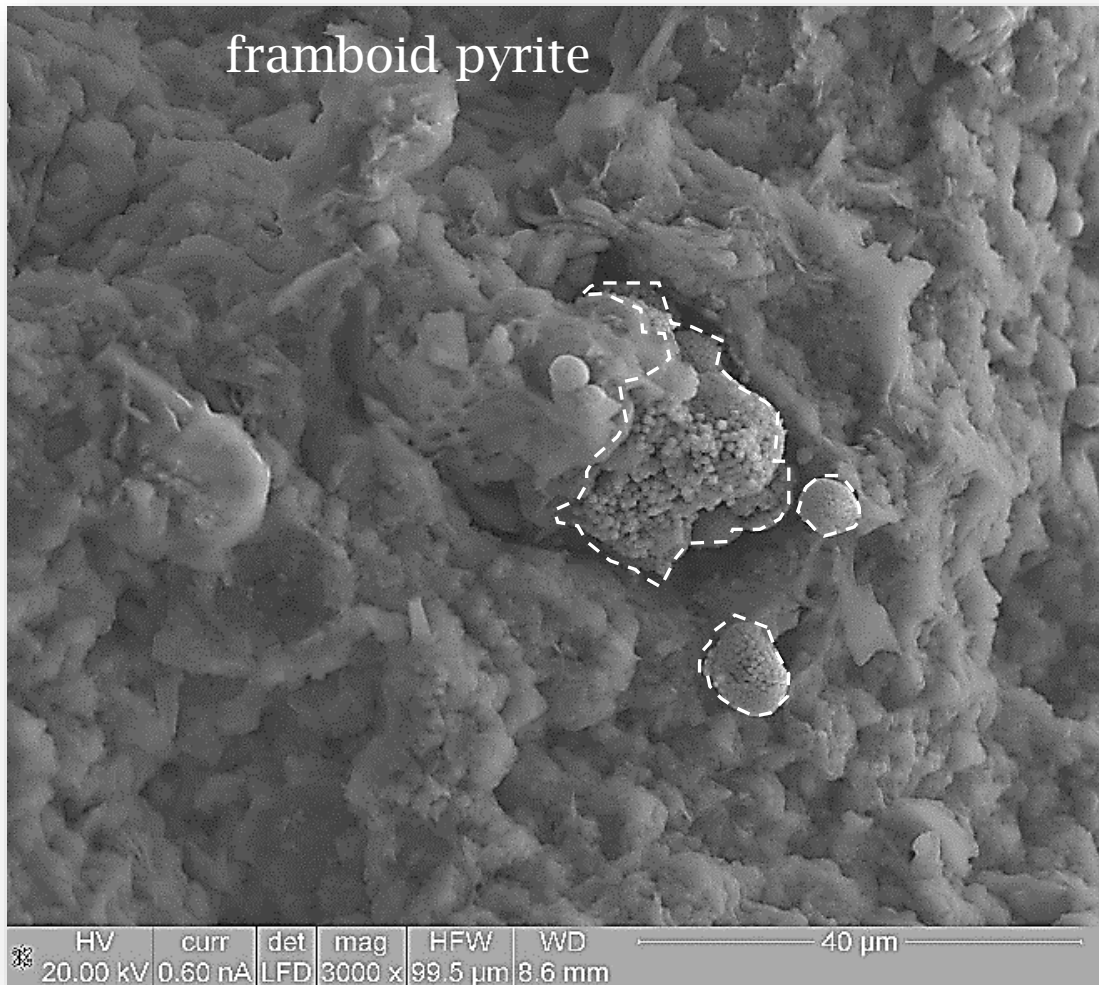
■ Lavato con acqua distillata, essiccato in forno e mischiato con acqua marina



# caratterizzazione dei sedimenti: approfondimenti







Highest content of pyrite



Presence of Sulphate  
reducers



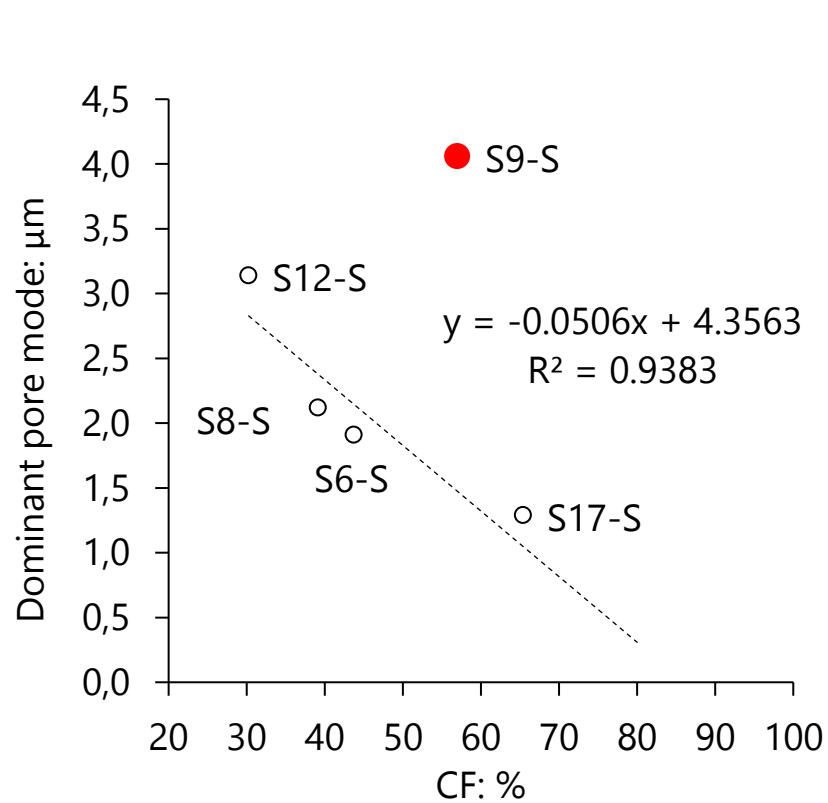
Sulphate reducers can use  
small organic molecules



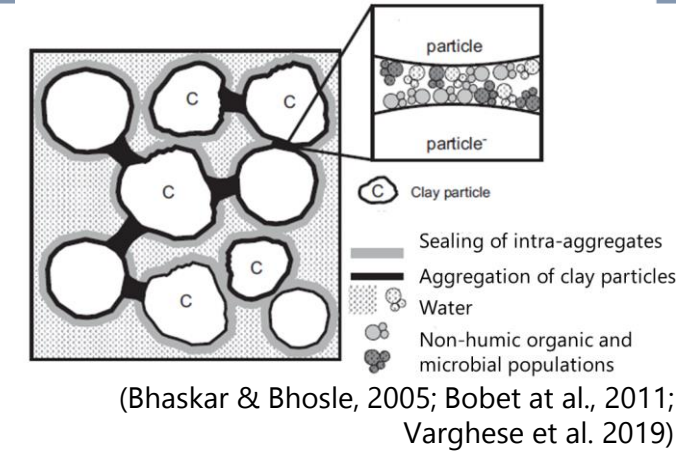
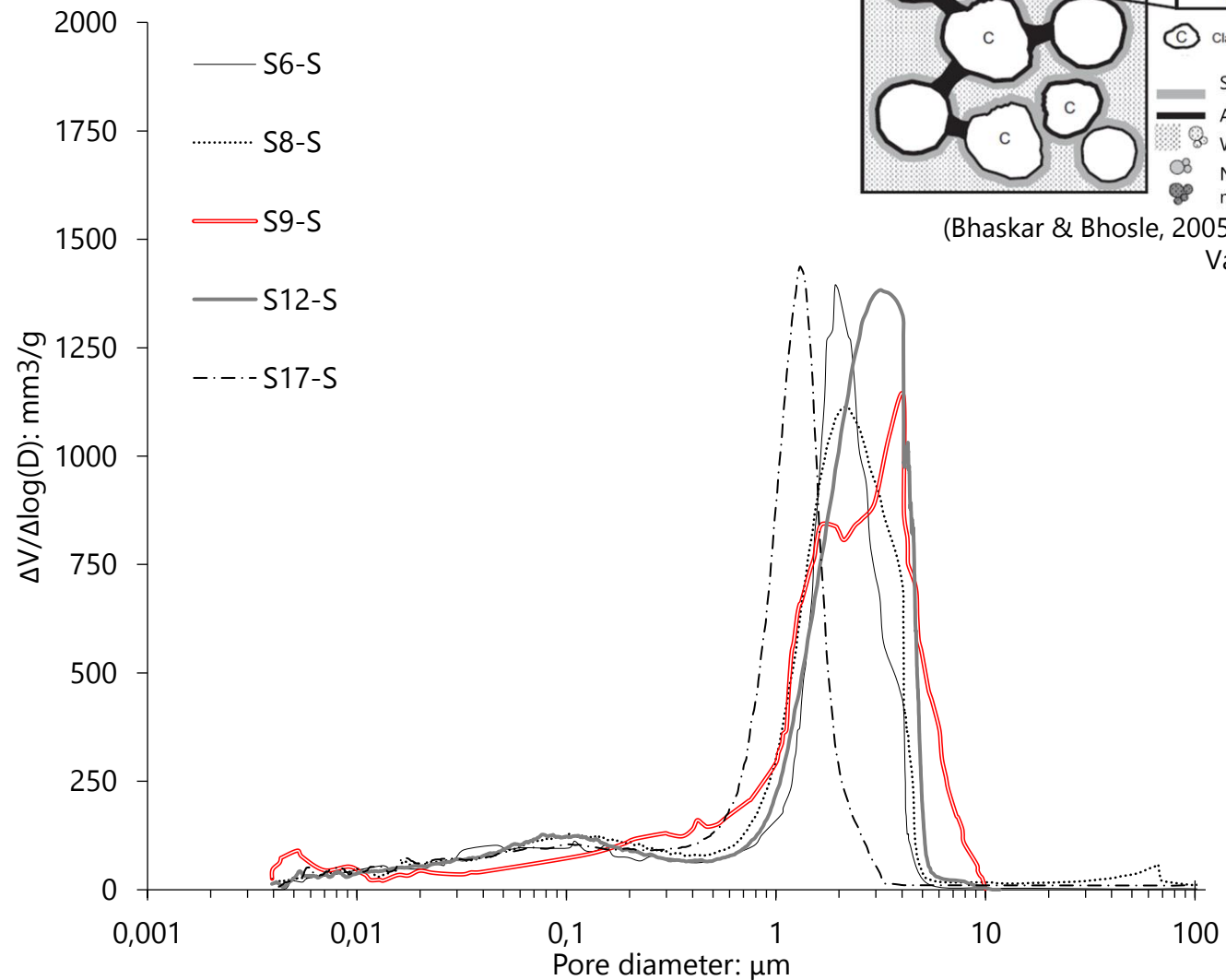
The microbial populations  
are necessary: they degrade  
complex organic  
compounds



# caratterizzazione dei sedimenti: approfondimenti

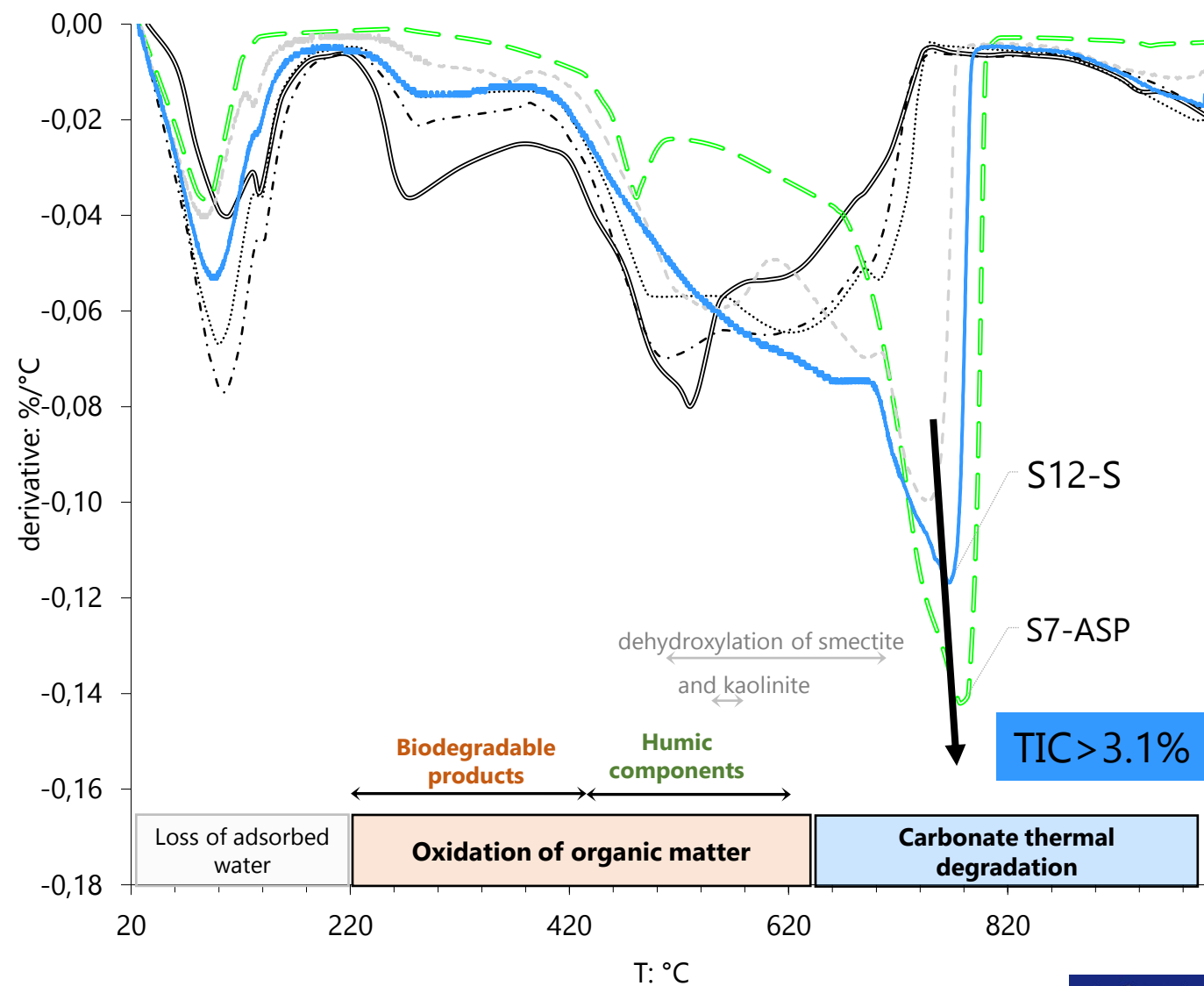
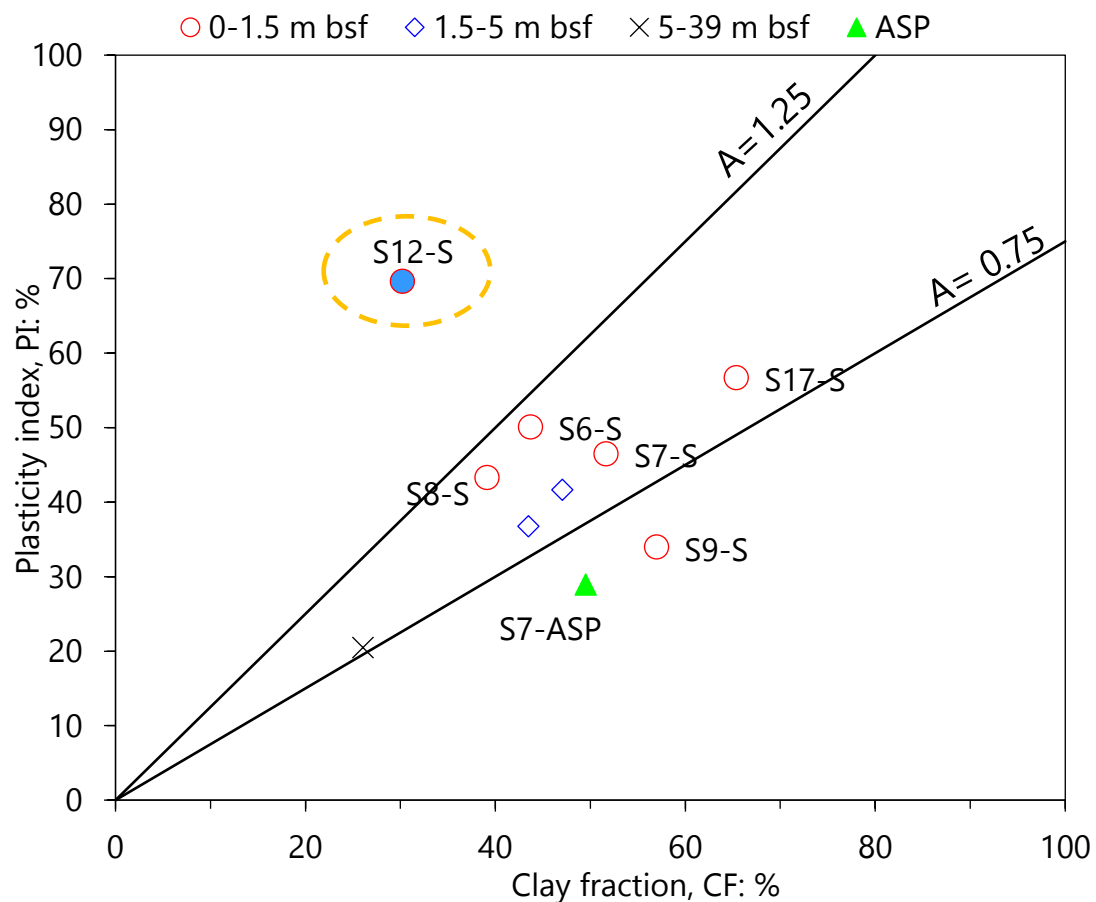


(Sollecito et al., 2021, Géotechnique)



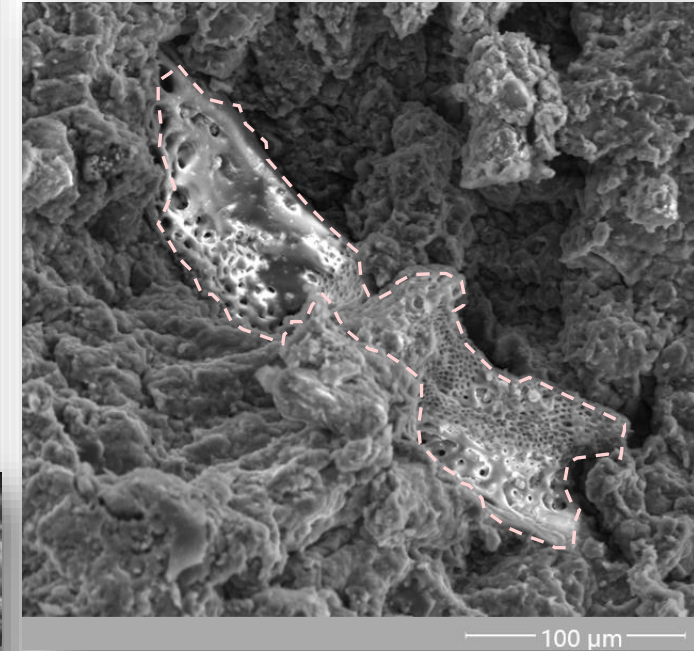
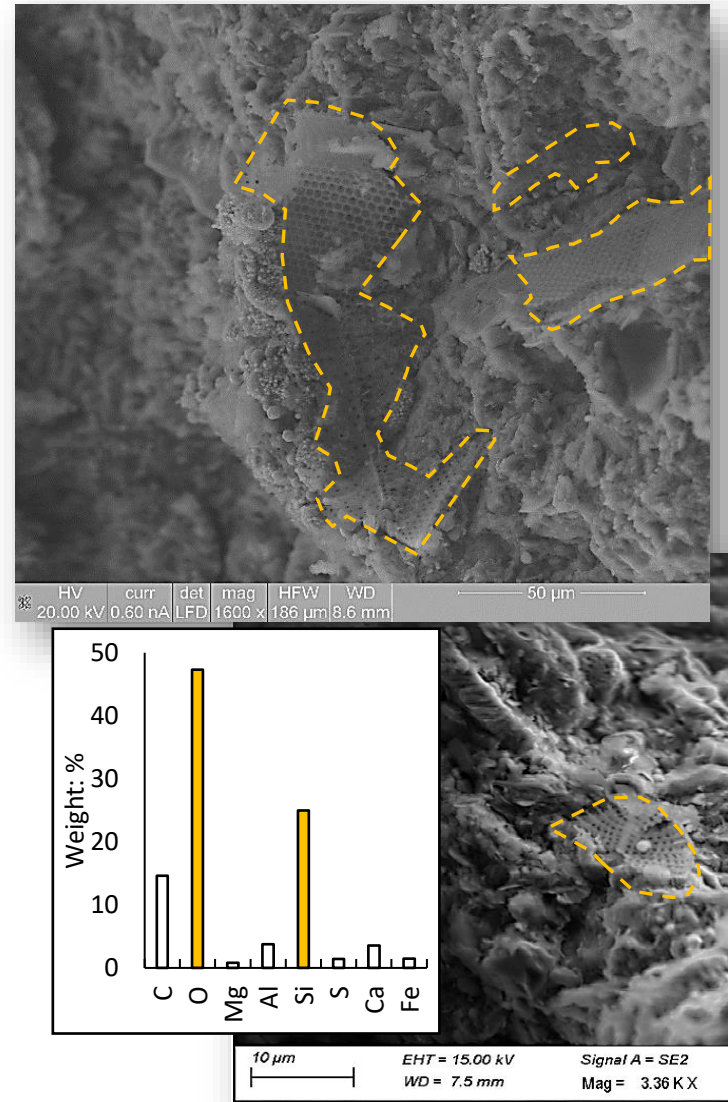
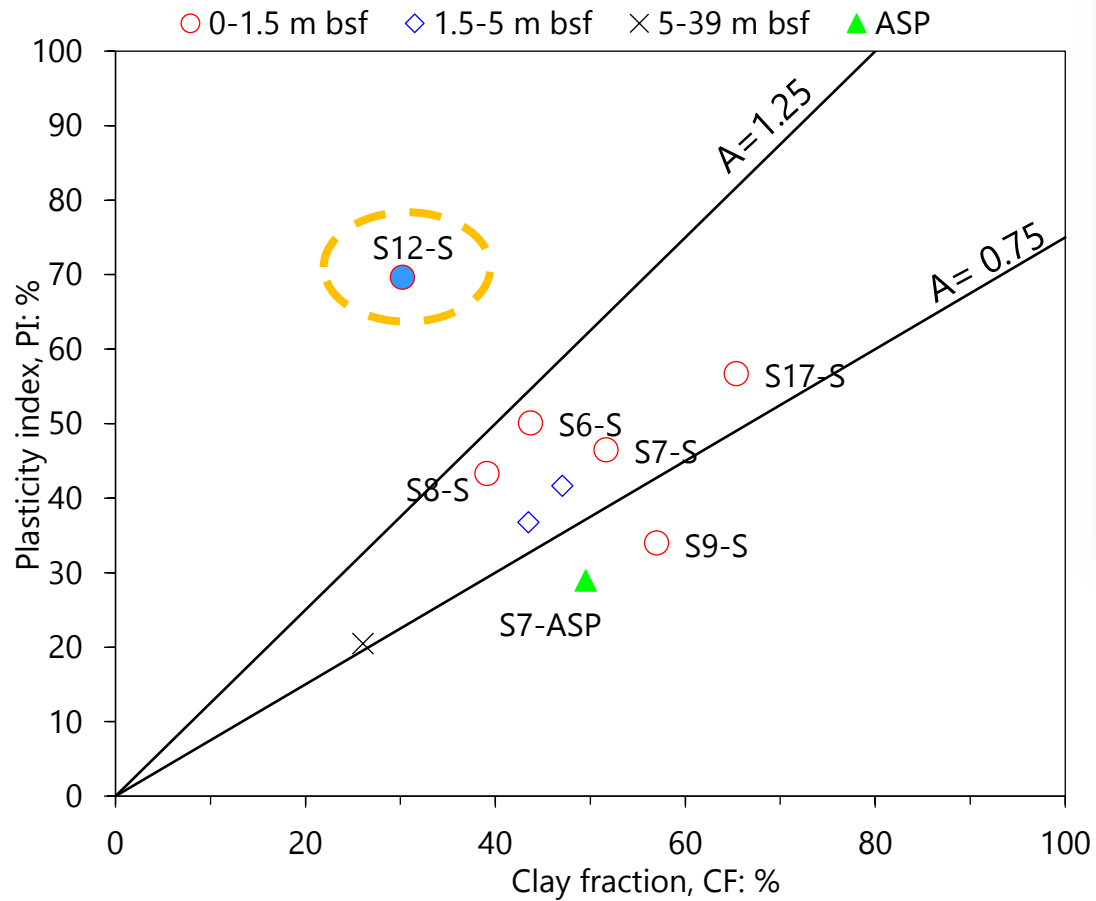


# caratterizzazione dei sedimenti: approfondimenti



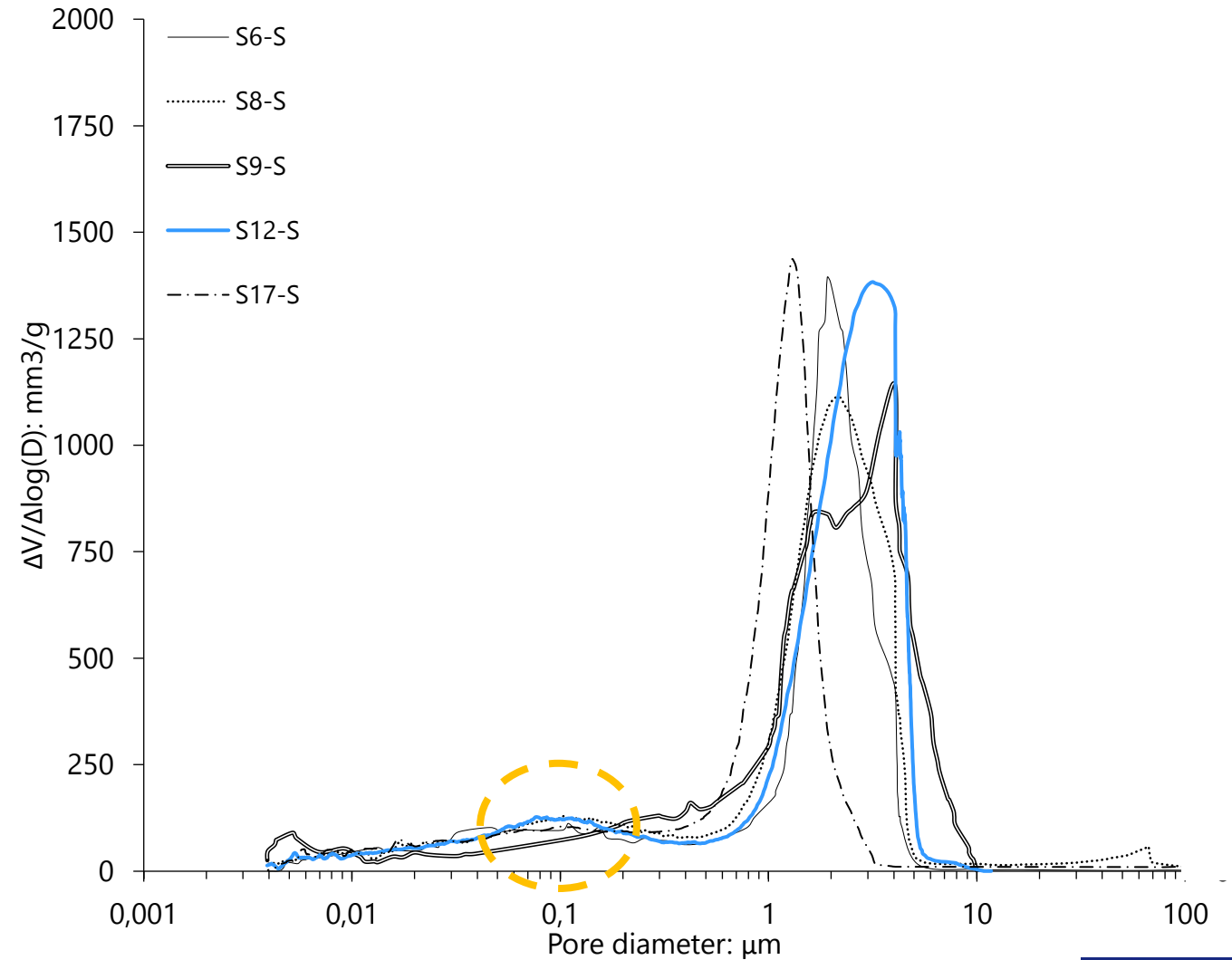
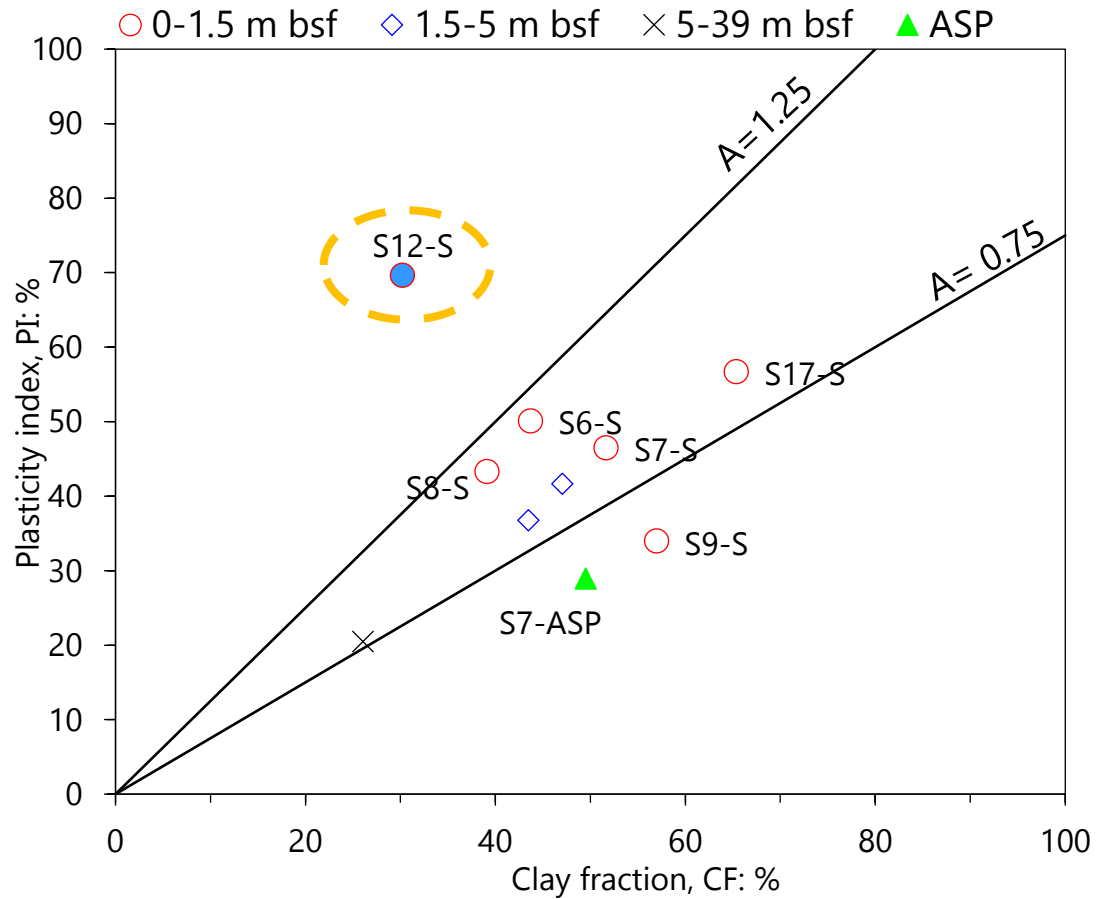


# i sedimenti di Taranto: approfondimenti



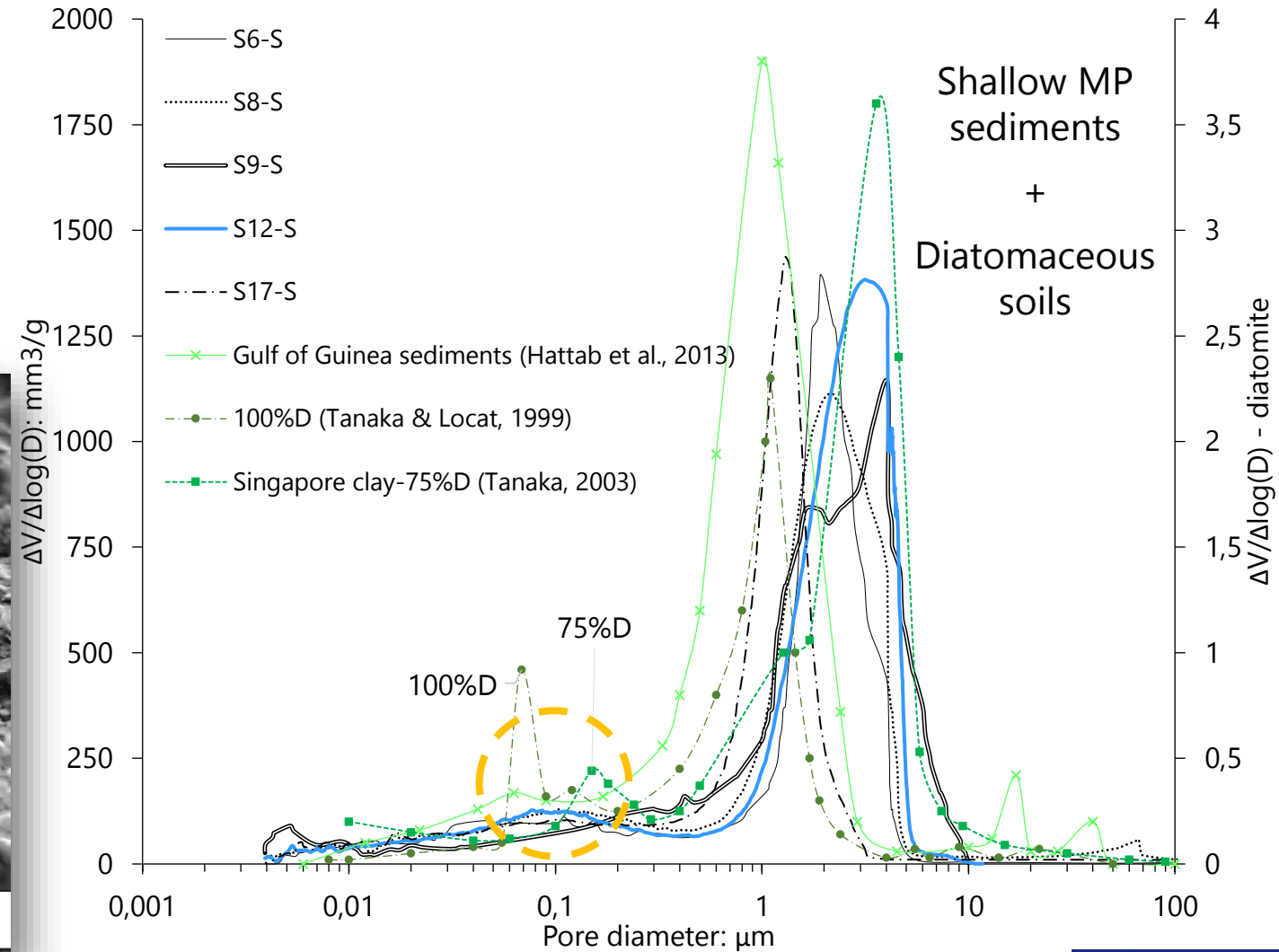
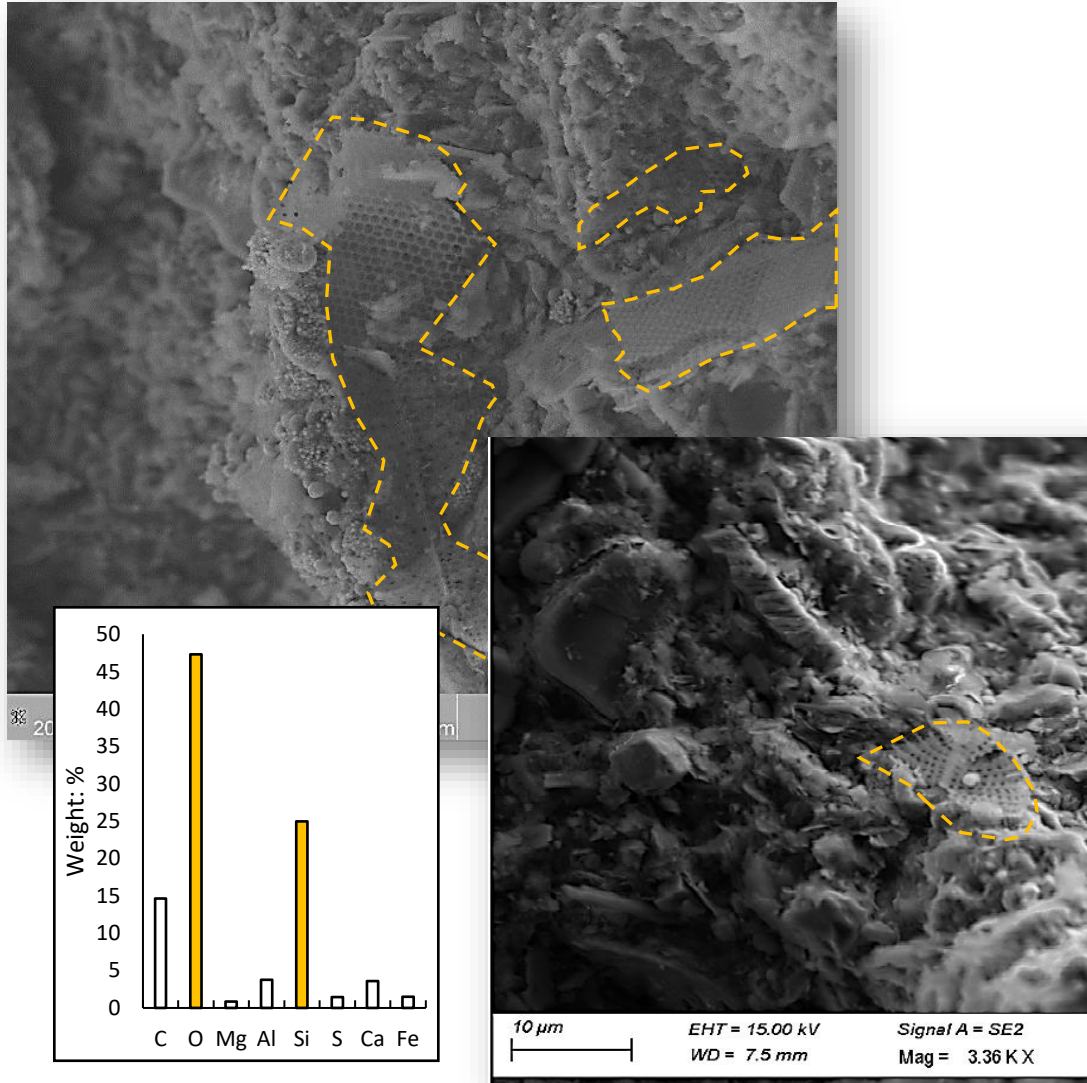


# caratterizzazione dei sedimenti: approfondimenti



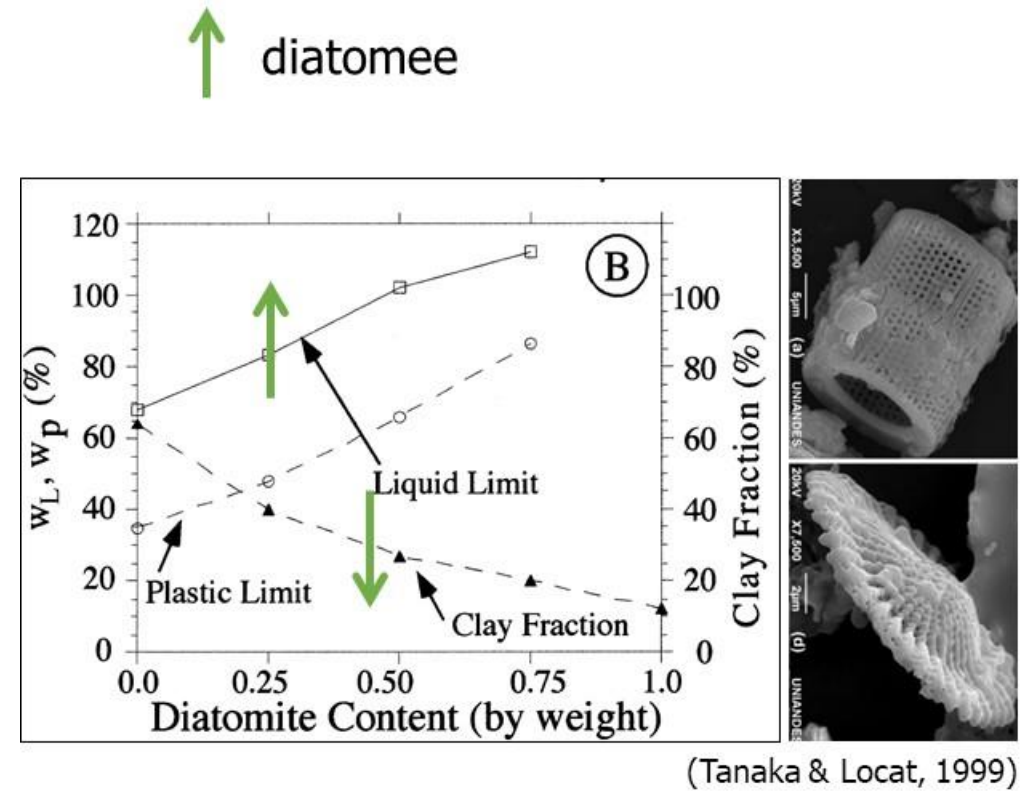
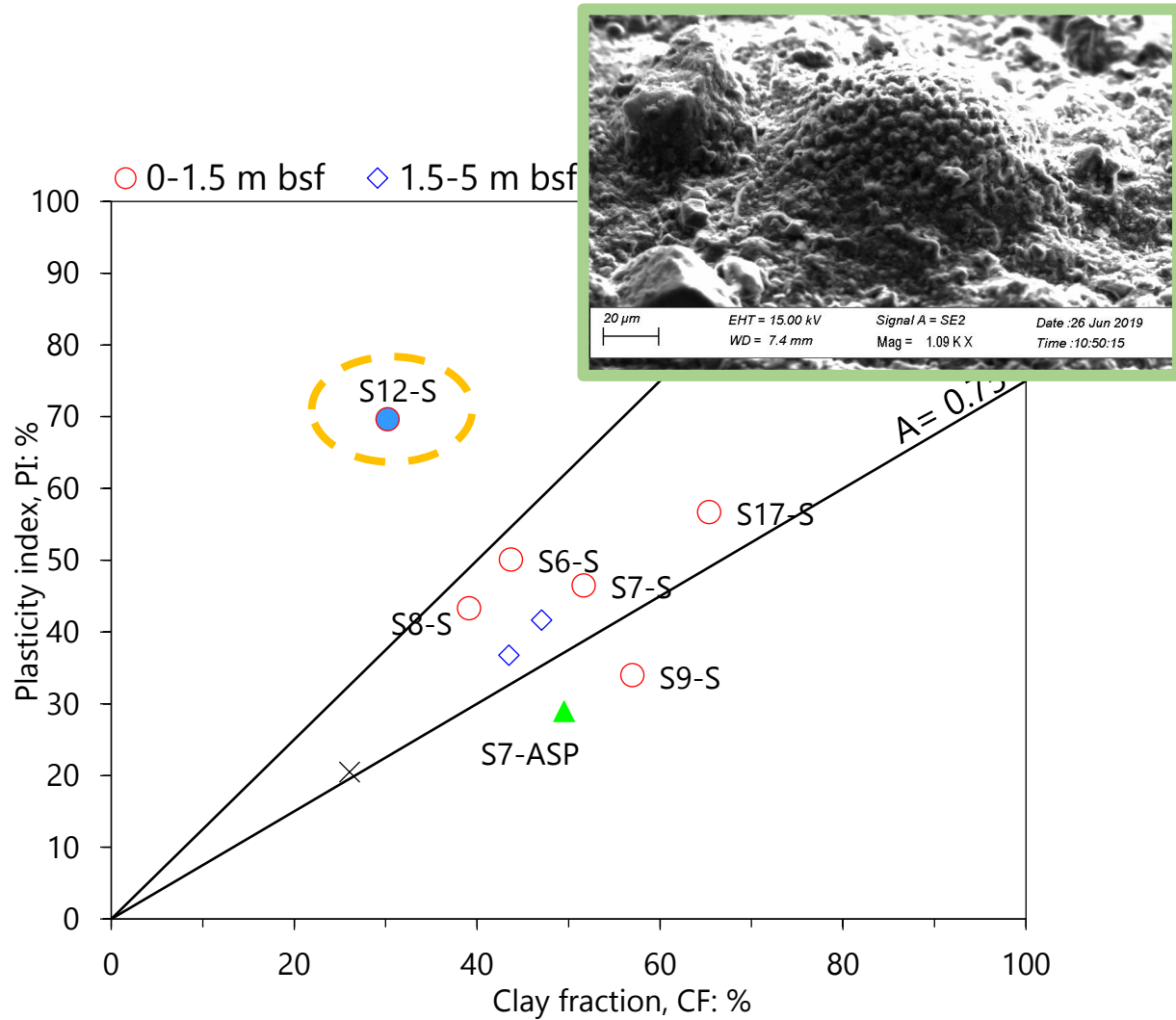


# caratterizzazione dei sedimenti: approfondimenti



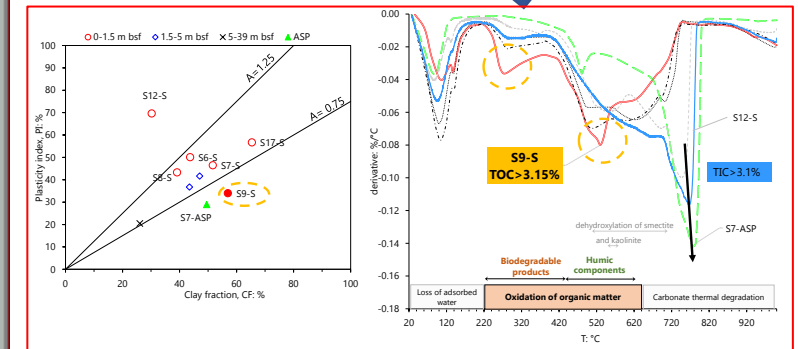
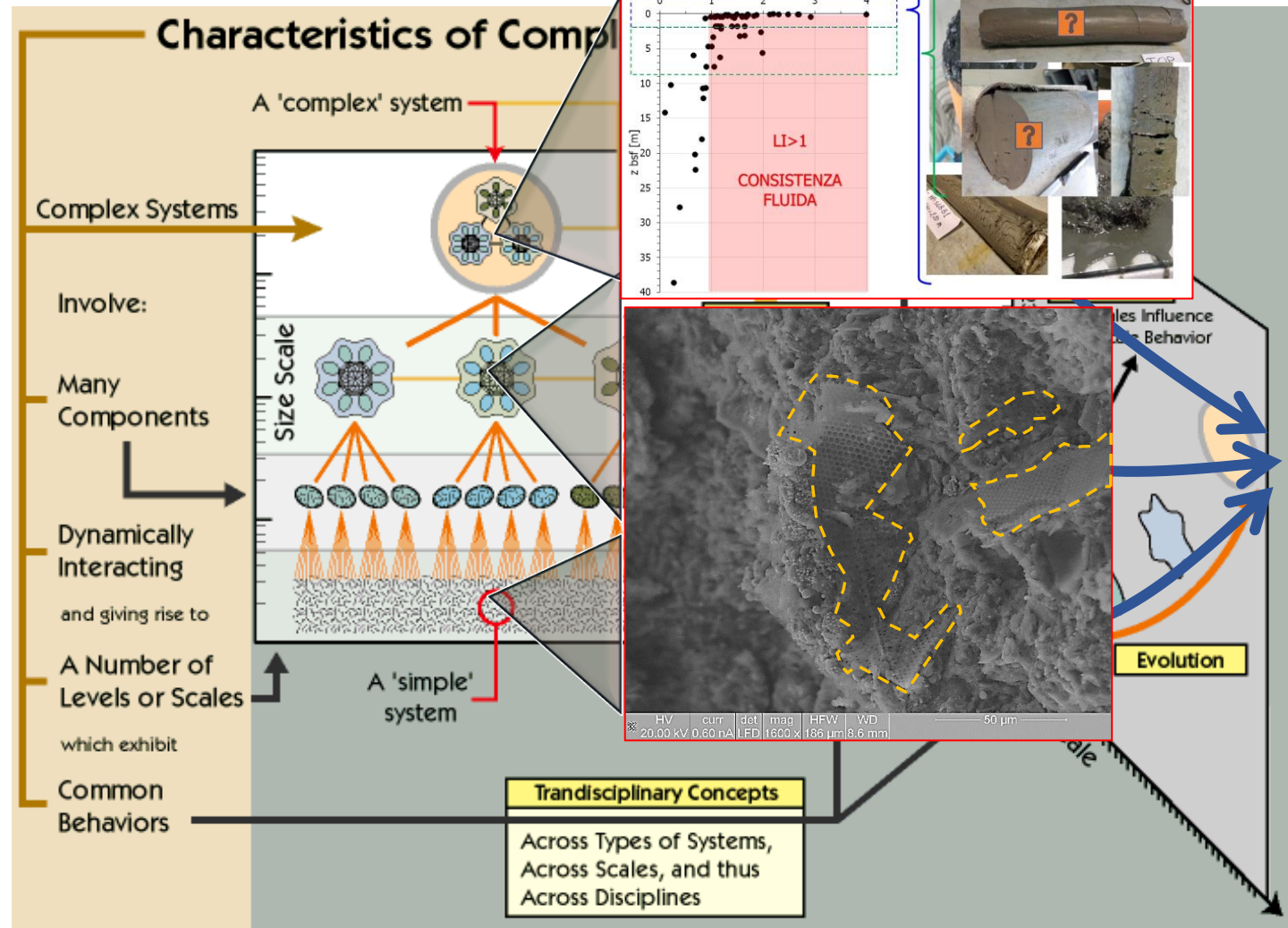


# caratterizzazione dei sedimenti: approfondimenti





# sistemi ambientali allo spigolo del caos



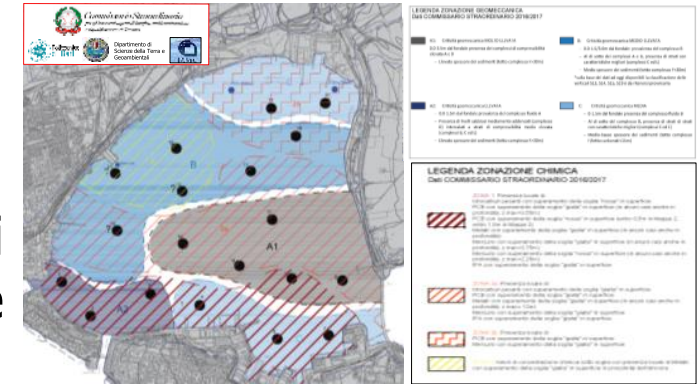
<<It often happens that environmental systems are **complex adaptive systems**, that operate as much as possible at the so-called **edge-of-chaos**.>>

(Baranger, 2002)



## Siti marini contaminati complessi: che struttura deve avere il modello concettuale di sito?

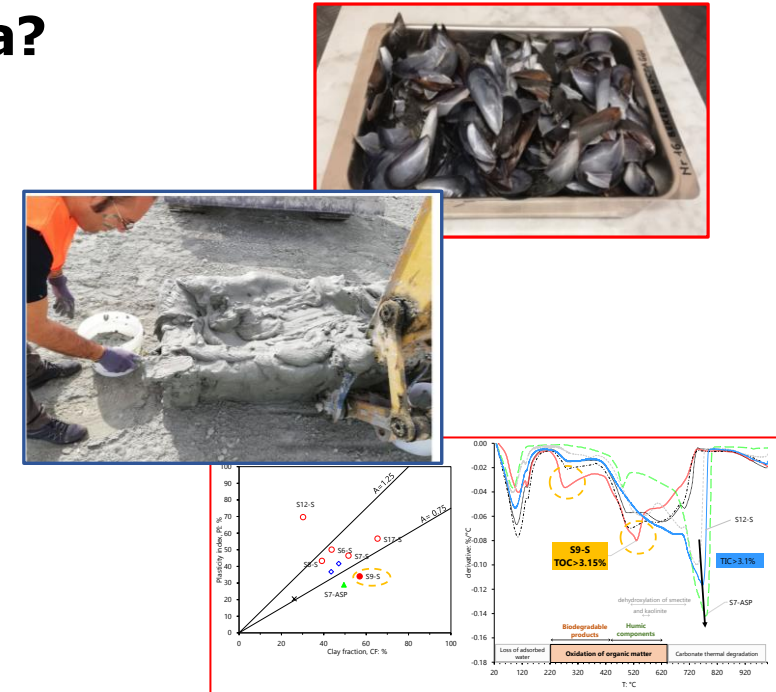
**It's complex. Let's deal with it.** La complessità ambientale di alcuni siti necessita di approcci che coinvolgano scienze di base e scienze applicate (CDSM).



## Focus sui sedimenti marini: da scarto a risorsa?

Il riuso ex-sito dei sediment con **l'utilizzo di MSP** sembra fornire risultati incoraggianti. La ricerca è in corso anche per verificarne l'efficienza chemo-meccanica per sedimenti contaminati.

**I conti non sempre tornano.** In alcuni casi, non si può prescindere da indagini **integrate e multiscale** per la **determinazione delle** proprietà geo-chemo-idro-meccaniche dei materiali.







courtesy of @micheledepape

*La poesia della terra non muore mai*  
John Keats