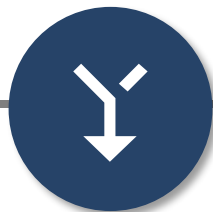


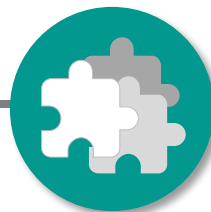
Dalla cartografia geologica alla modellazione geologica 3D: metodi, strumenti e casi di studio

CHIARA D'AMBROGI

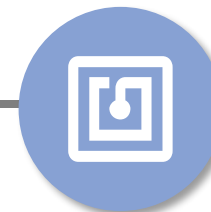
Servizio Geologico d'Italia - ISPRA



**DAL FOGLIO AL
MODELLO 3D**

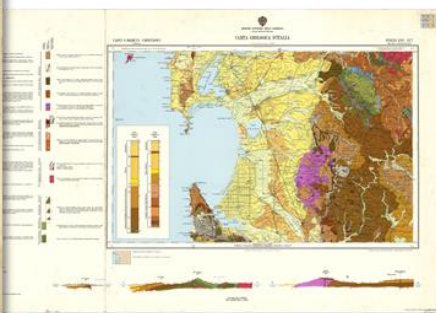


**TECNICHE DI
MODELLAZIONE**

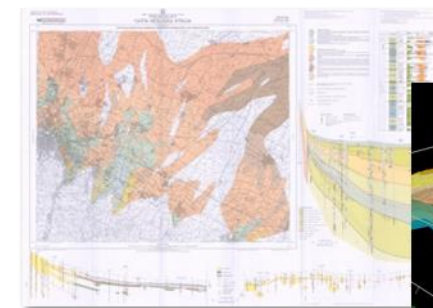


APPLICAZIONI

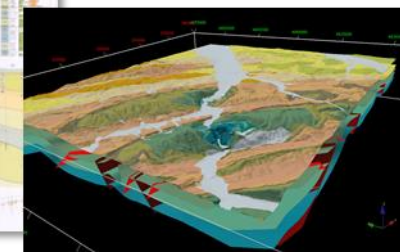
277 fogli



Carta geologica 100k



26 fogli/modelli 3D



Sottosuolo

1860

1900

1960

2000

2020

17 plastici

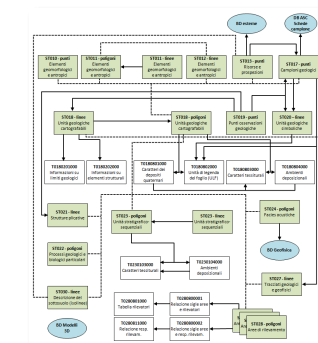
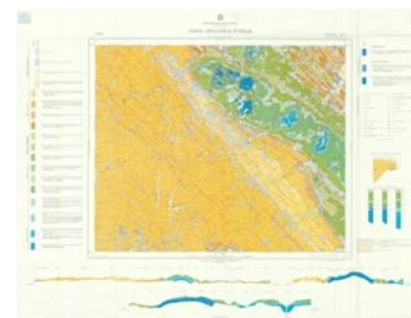
Piani-rilievo

Legge 68
Organi cartografici dello Stato

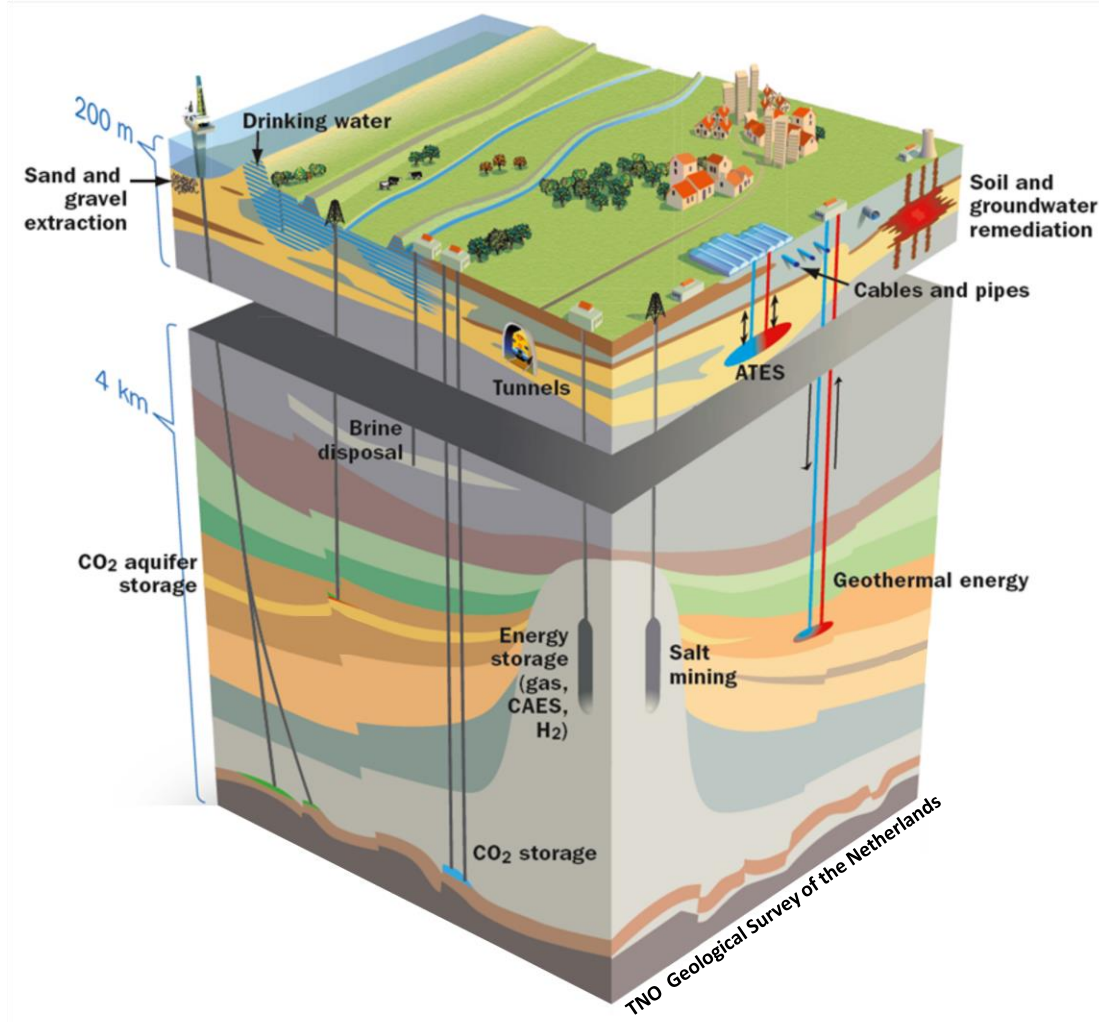
Carta geologica 50k

Progetto CARG

45% completati



SOTTOSUOLO è la frontiera



SUSTAINABLE DEVELOPMENT GOALS



- Gestione aree urbane e infrastrutture
- Risorsa geotermica
- Risorse idriche
- Materiali da estrazione
- Gestione dei siti di bonifica
- Stoccaggio energetico
- Stoccaggio geologico della CO₂
- Pericolosità geologiche (faglie attive e sorgenti sism., subsidenza)

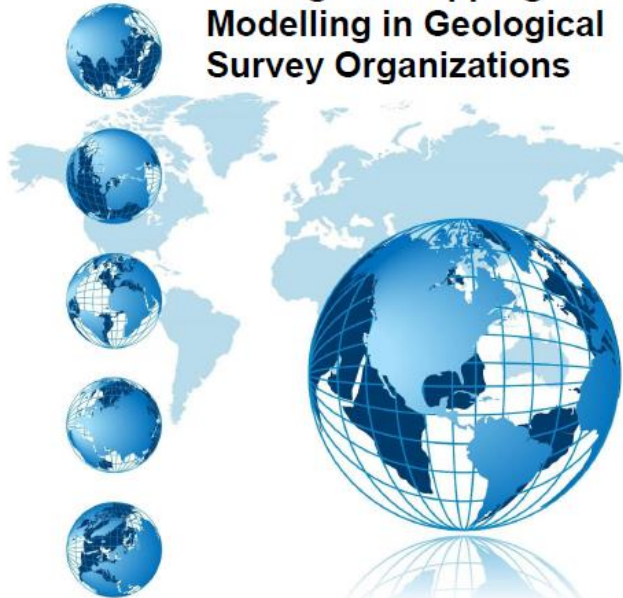
International 3D Geological Modelling Community

AER/AGS Special Report 112



meeting biennale a Geological Society of America

2019 Synopsis of Current
Three-Dimensional
Geological Mapping and
Modelling in Geological
Survey Organizations



www.ags.aer.ca/publications/SPE_112.html



Comunità Accademica

European 3D Geological Modelling Community

Bern 2019



www.3dgeology.org

Denmark 2021 – physical meeting postponed to 2023



Geological Mapping and
Modelling Expert Group



Geological Information
and Modeling



Utilizzatori

Tavolo Geologia 3D di sottosuolo

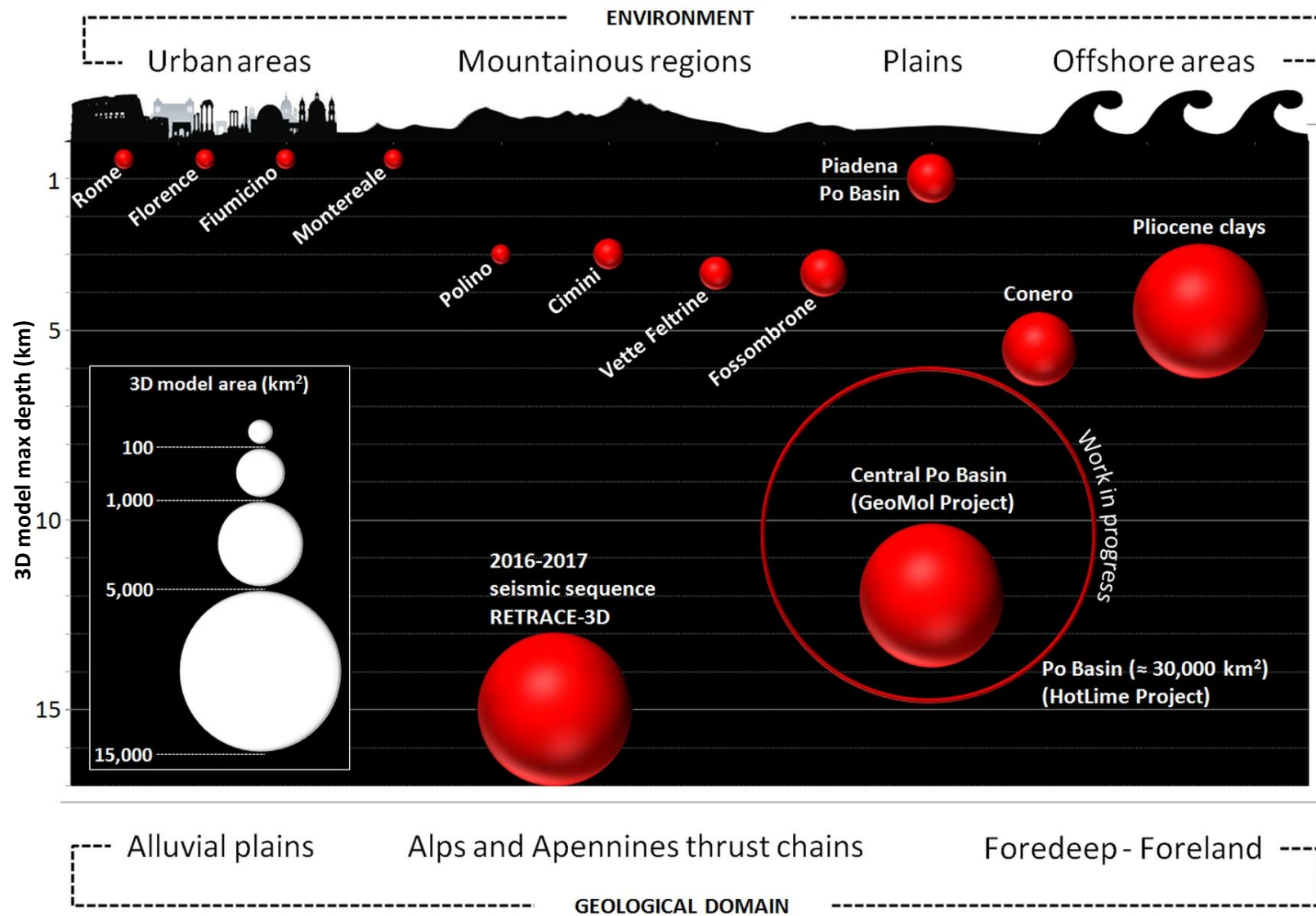


ISPRA e 10
regioni/prov. aut.



Modelli geologici
e termici

LA MODELLAZIONE GEOLOGICA 3D al SERVIZIO GEOLOGICO D'ITALIA



Il Progetto CARG e la geologia di sottosuolo

finanziamenti 1988-2004

25 fogli geologici con foglio di sottosuolo

1 foglio geologico con modello 3D

finanziamenti 2020-2022

11 fogli geologici con foglio di sottosuolo e modello 3D

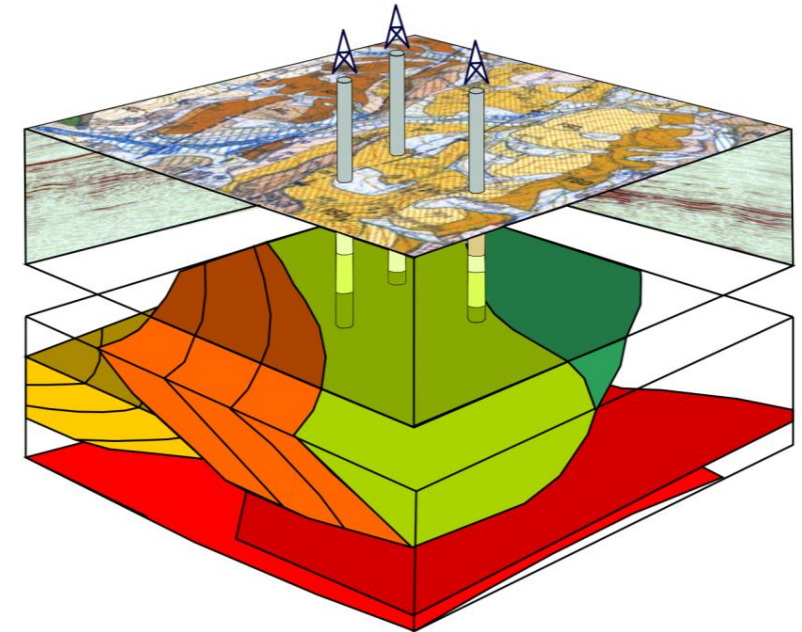
13 fogli geologici con modello 3D

36 fogli geologici di sottosuolo

25 modelli 3D



- comprendere e visualizzare le strutture geologiche nella loro forma più completa
- verificare ipotesi e migliorare la congruenza geometrica del foglio
- integrare dati diversi (di superficie e sottosuolo, geologici e geofisici) e massimizzarne il loro contenuto informativo
- fornire agli utilizzatori uno strumento molto potente per numerose applicazioni



- Utilizzo prevalente di dati da rilevamento geologico



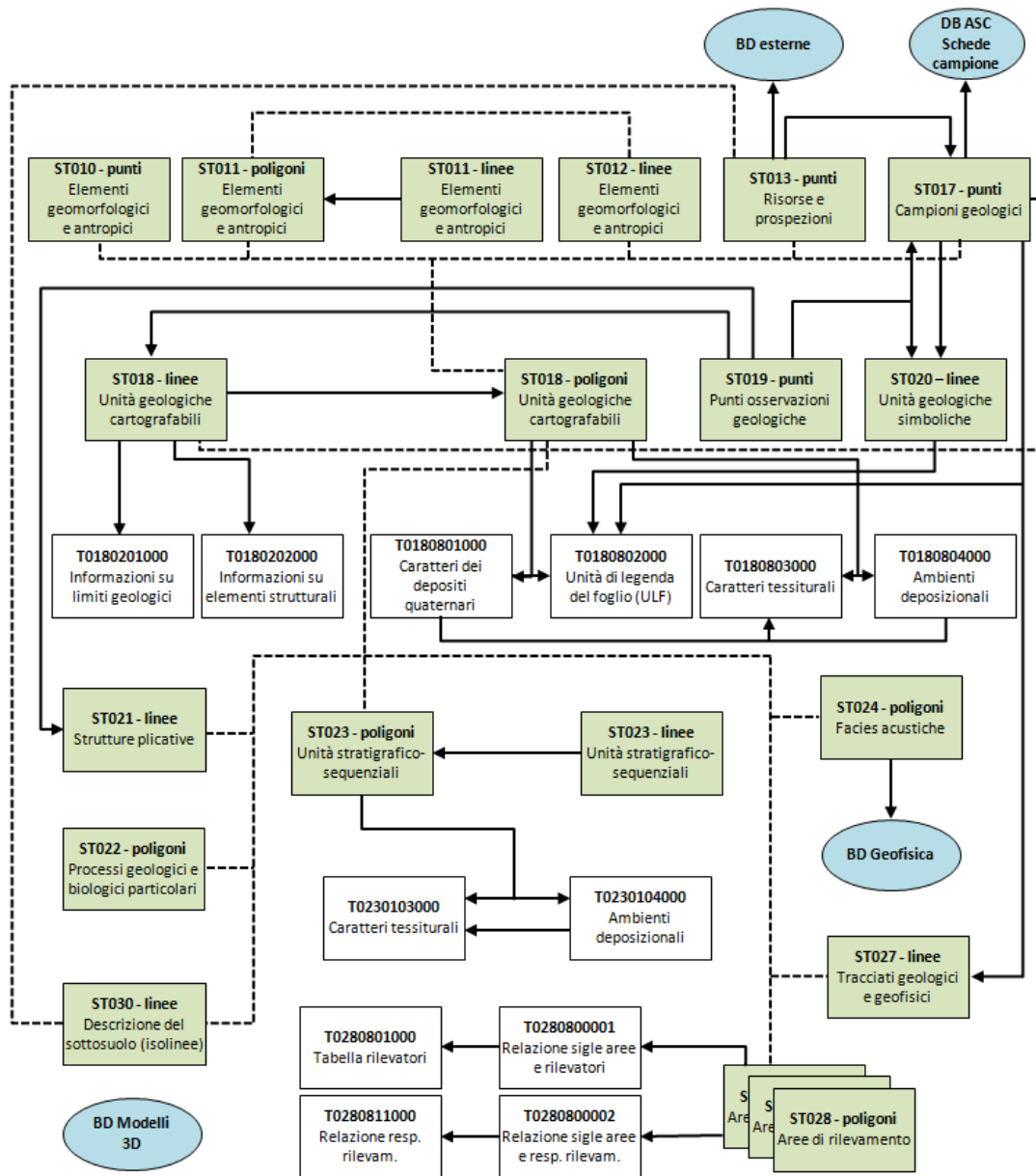
- Utilizzo prevalente di dati di sottosuolo (sismica e pozzi)

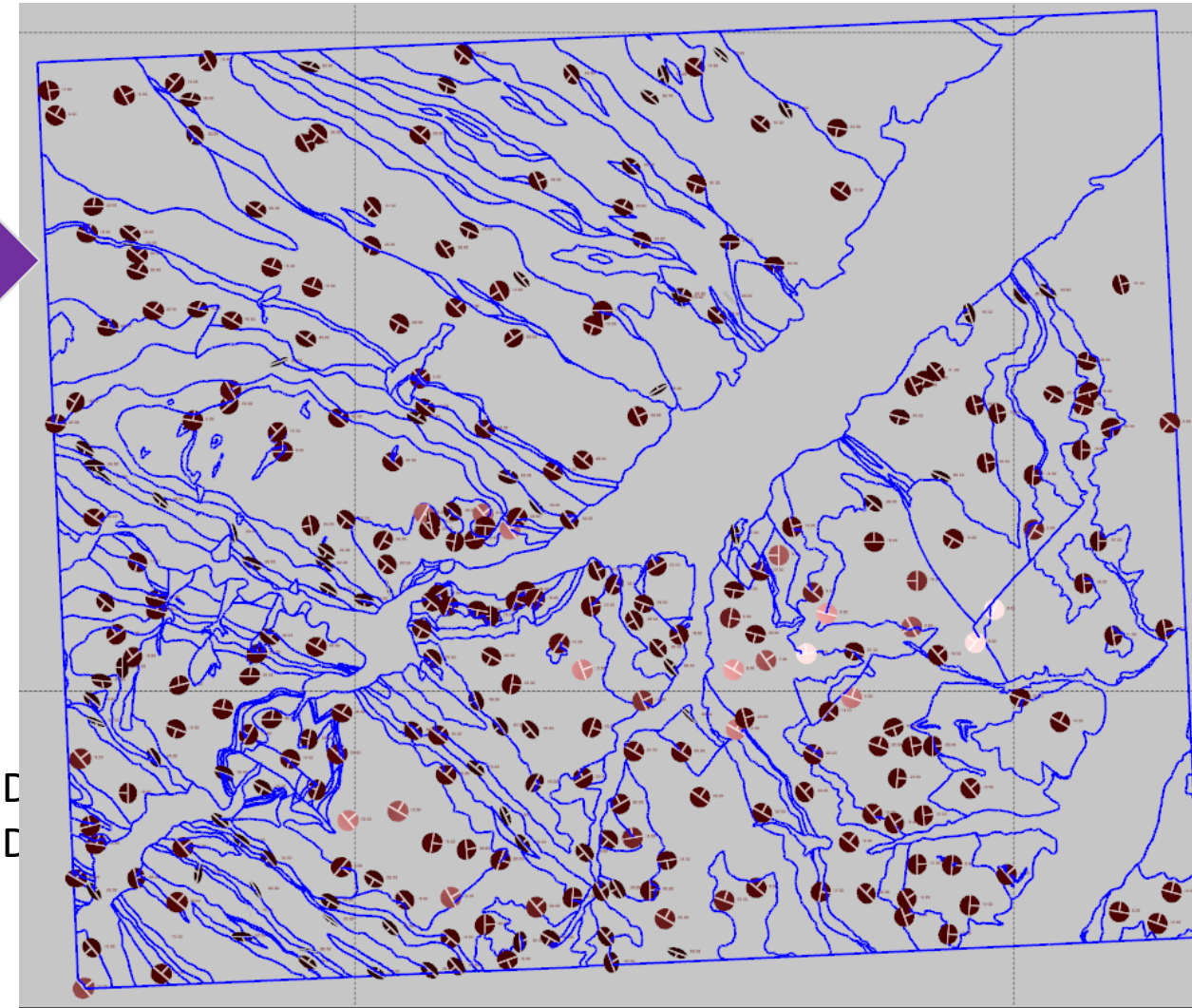
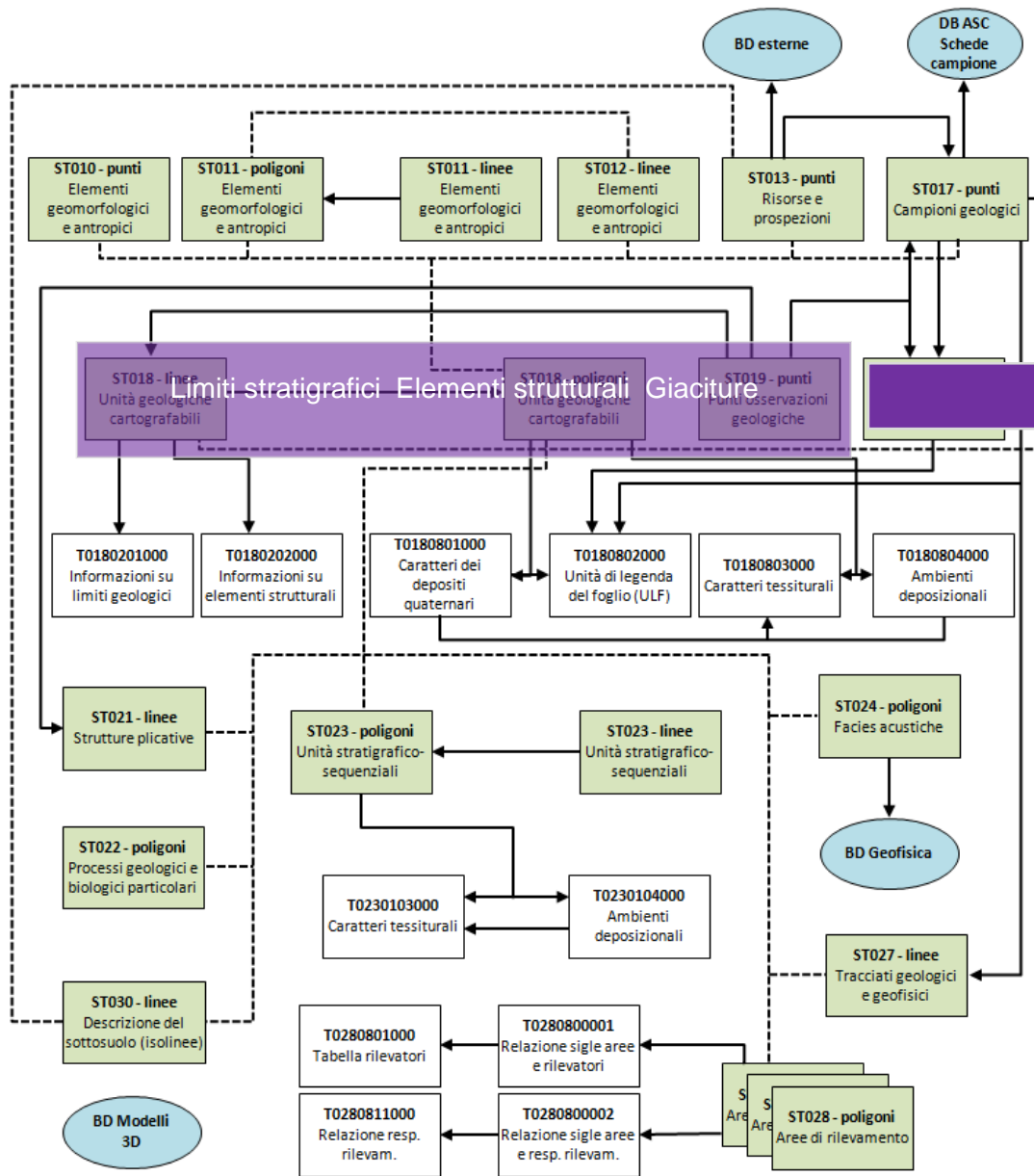
- = Raccolta e analisi dei dati per il modello 3D procede parallelamente alla raccolta dei dati per il foglio
Legenda comune tra foglio di superficie e modello 3D, stesse unità - a meno di specifiche esigenze
- ≠ Flusso di lavoro per la costruzione di un modello 3D

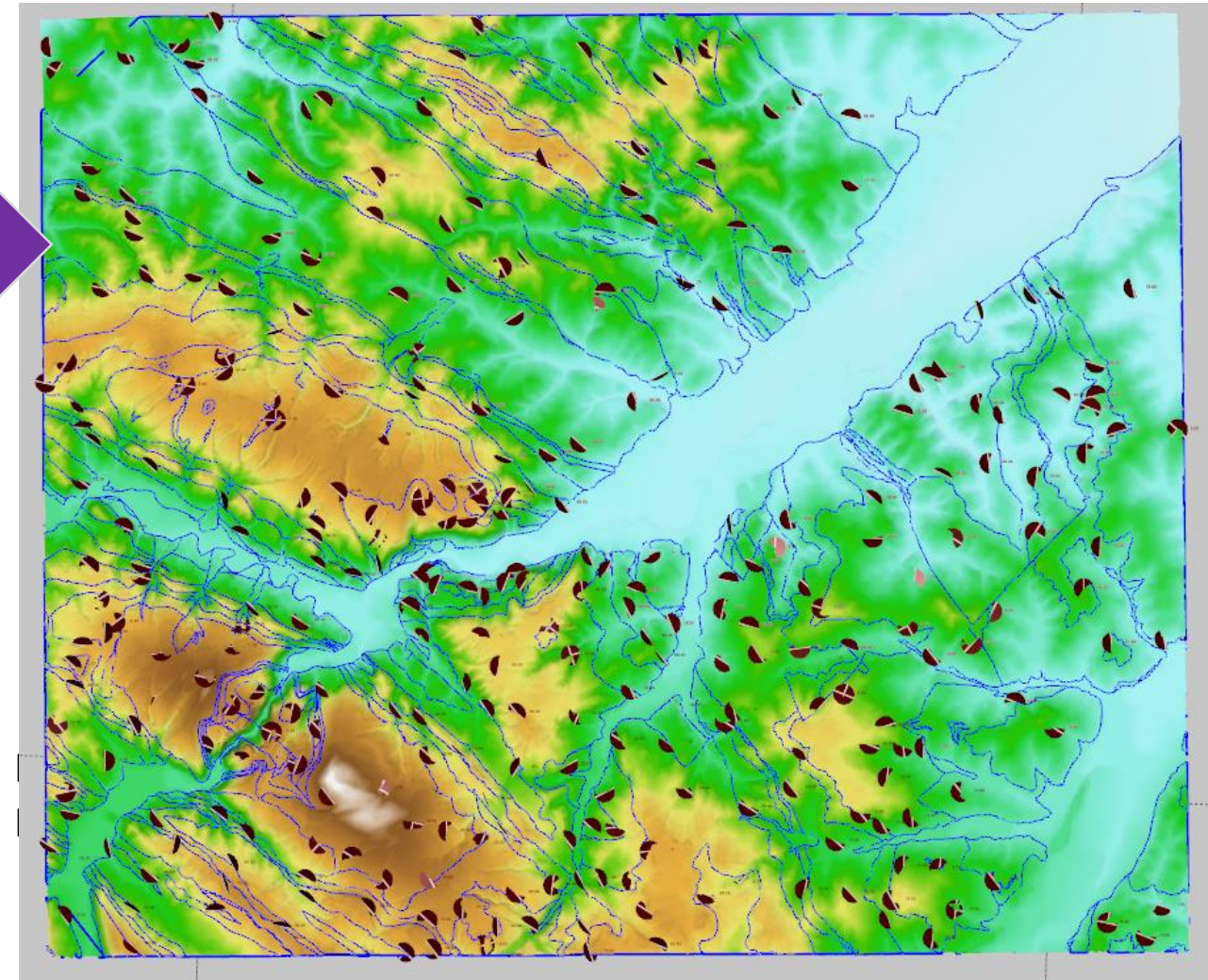
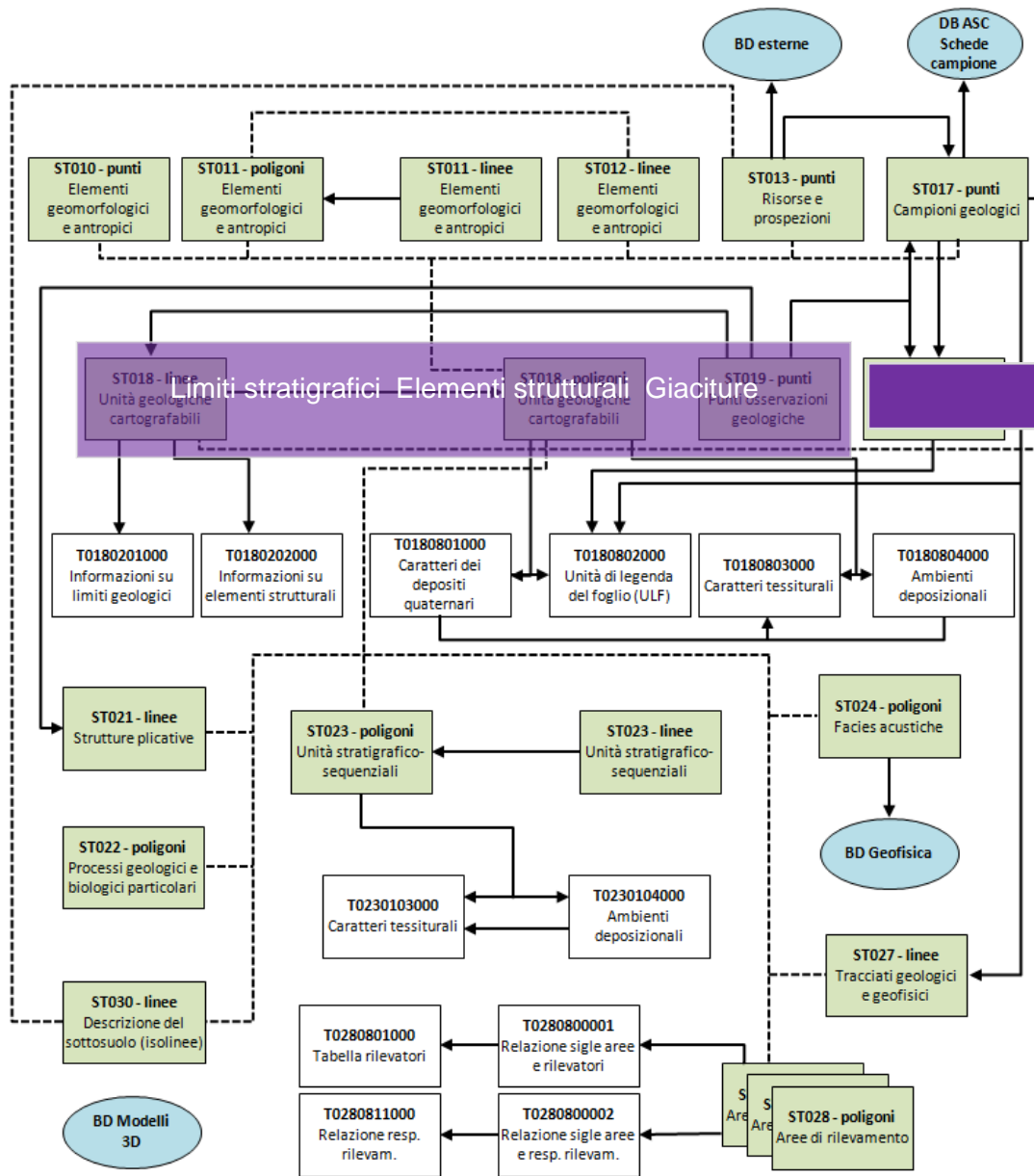
- Utilizzo prevalente di dati da rilevamento geologico

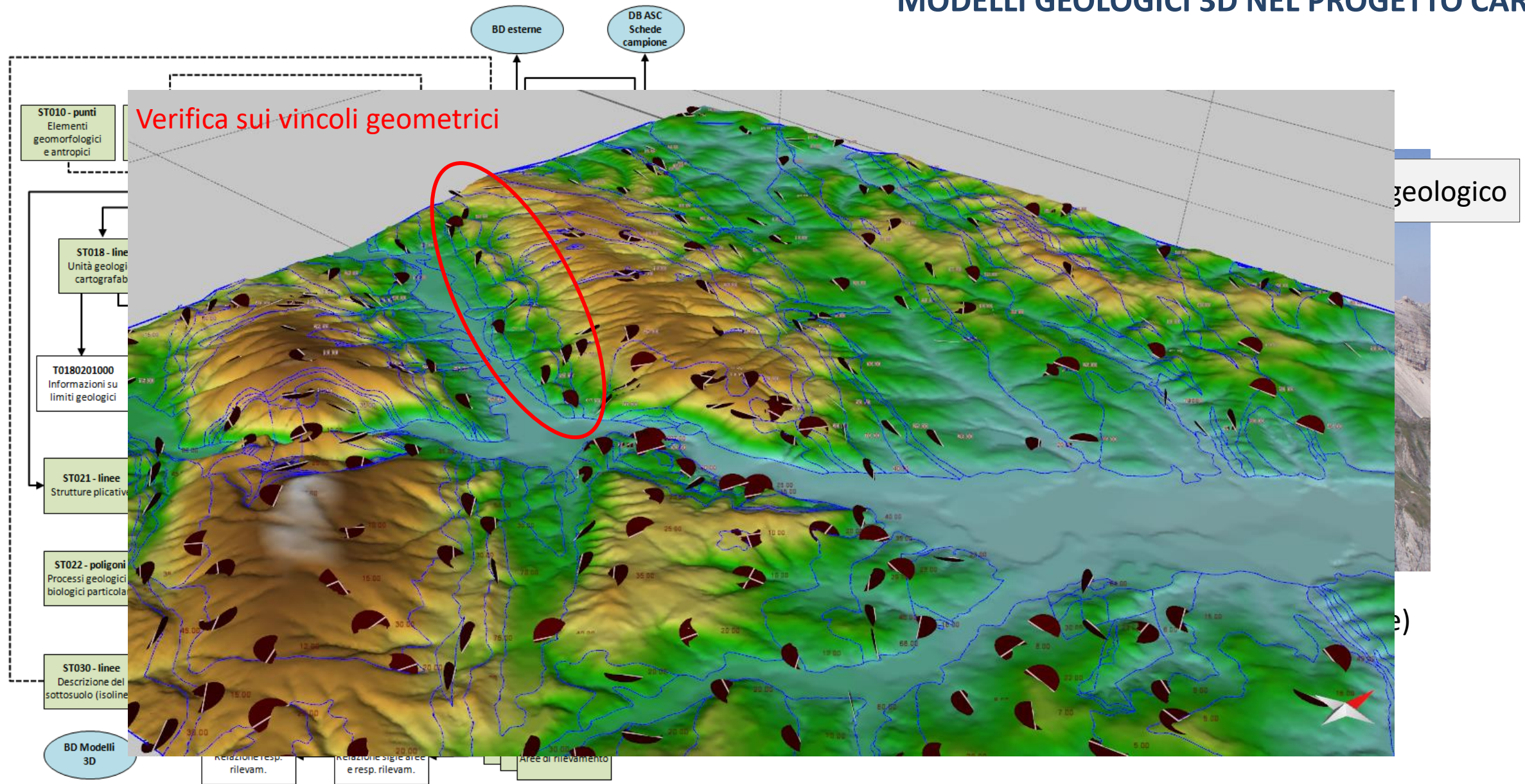


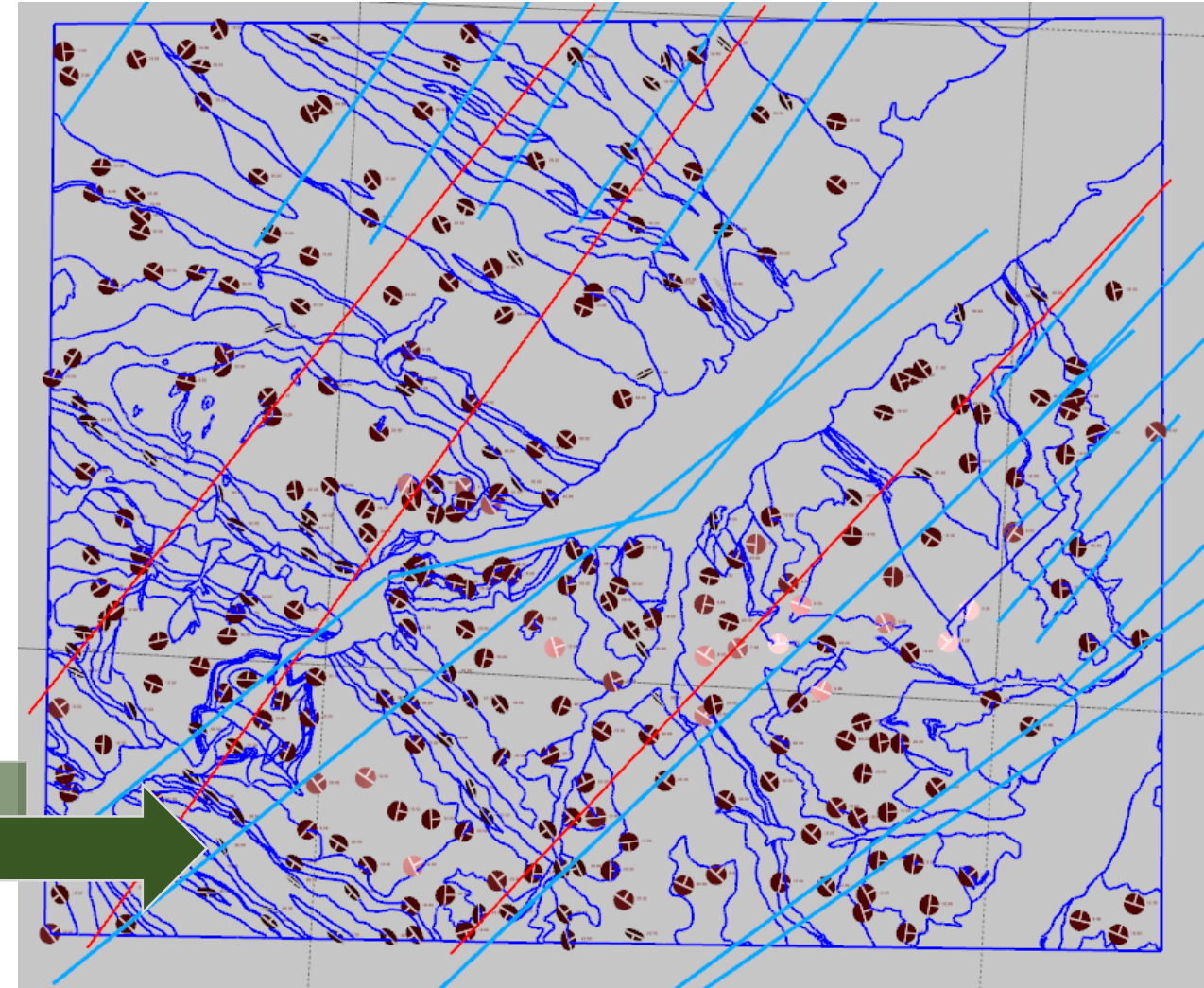
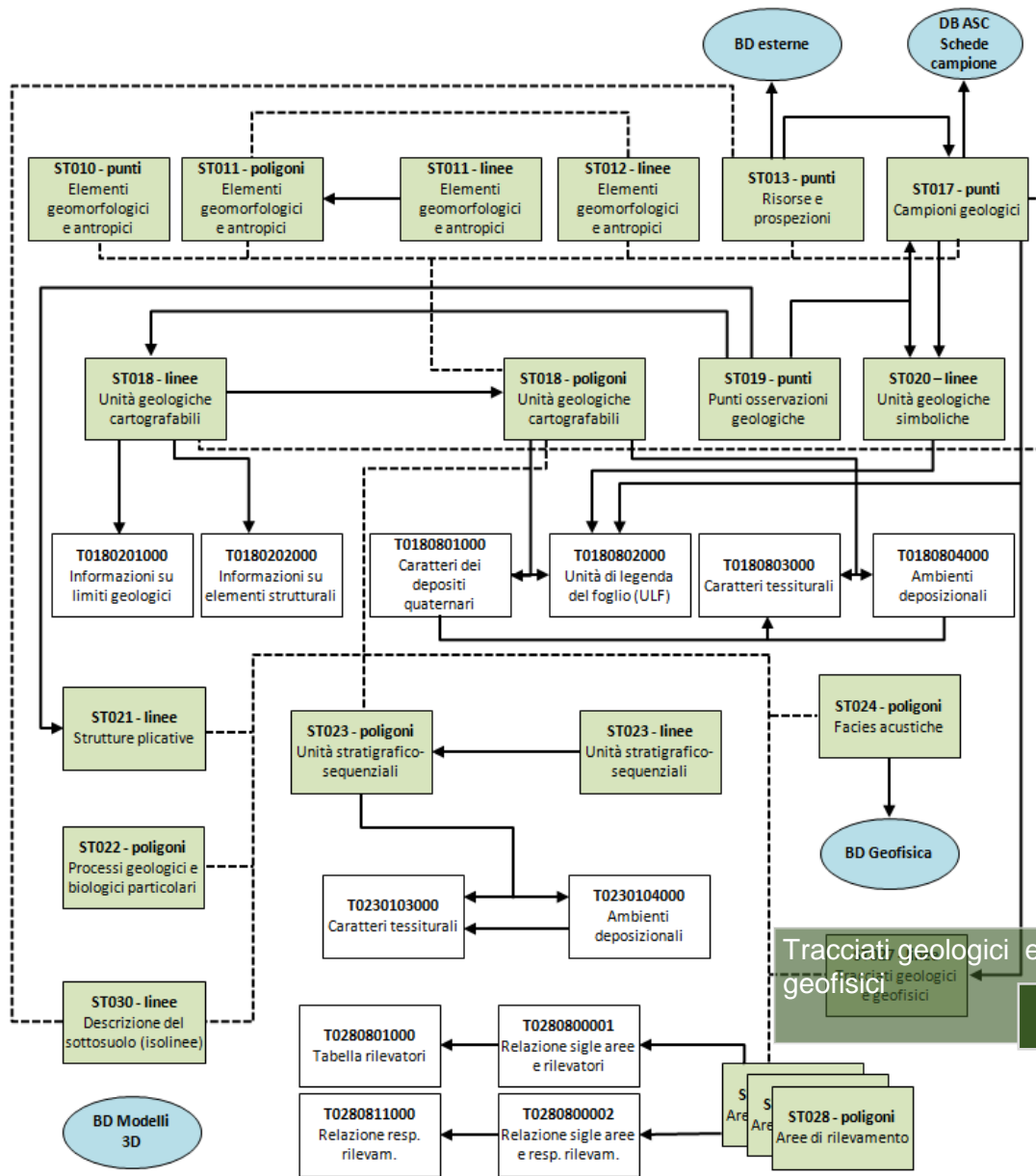
- Definire modello concettuale (con foglio di superficie)
- Definire gli oggetti da modellare (quale obiettivo?)



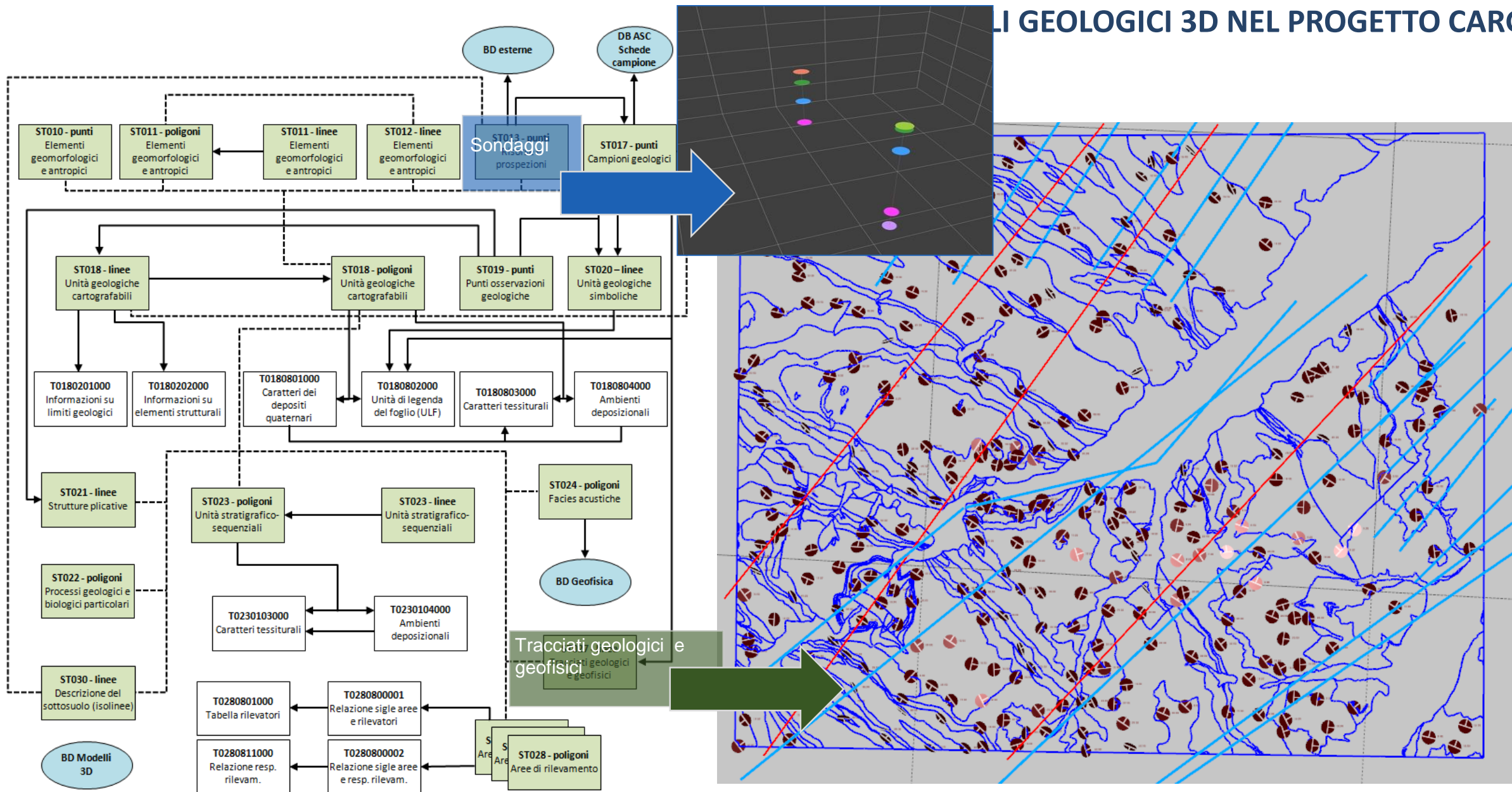


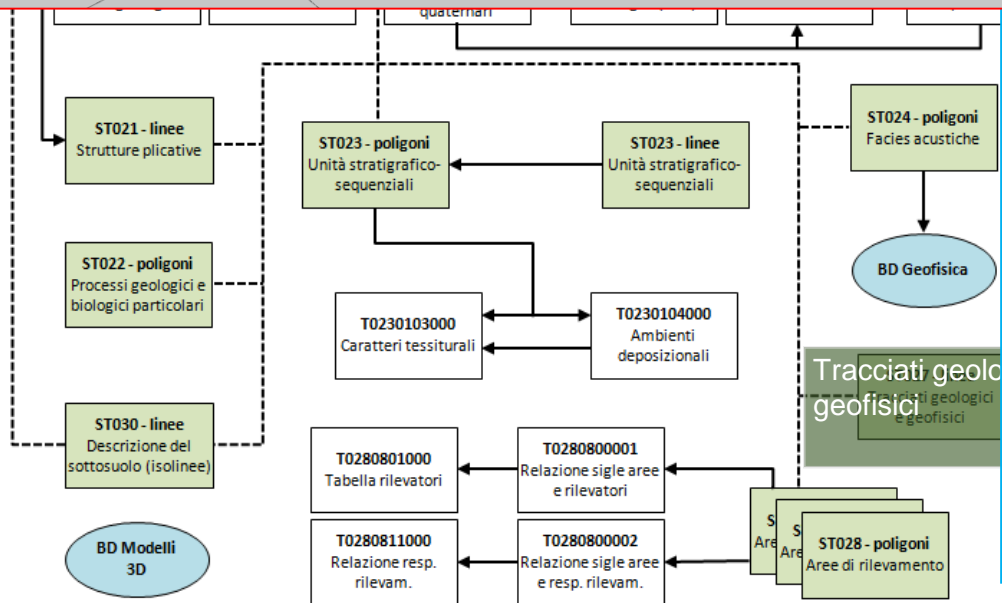
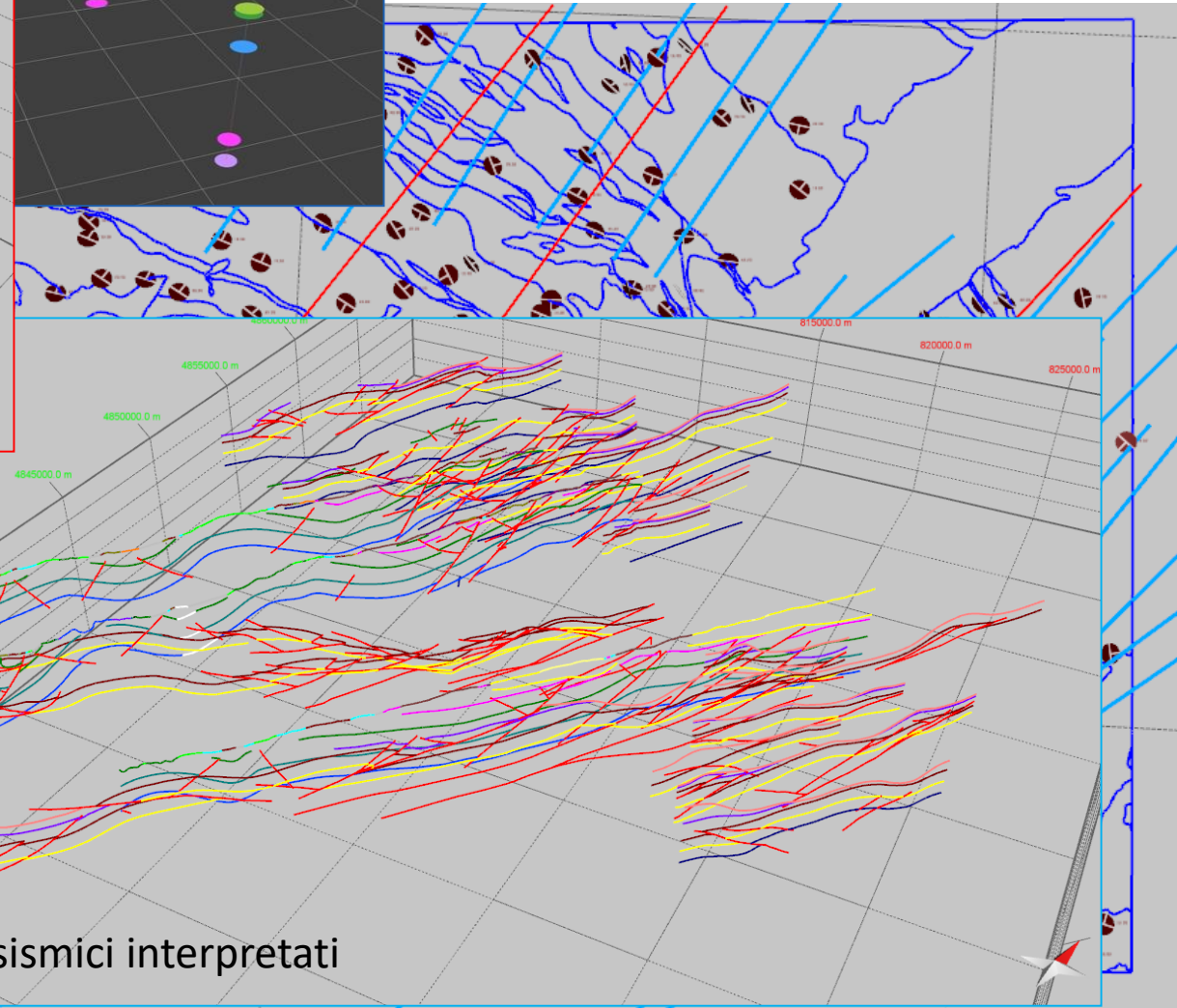
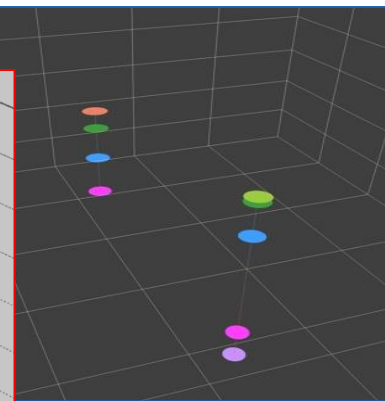
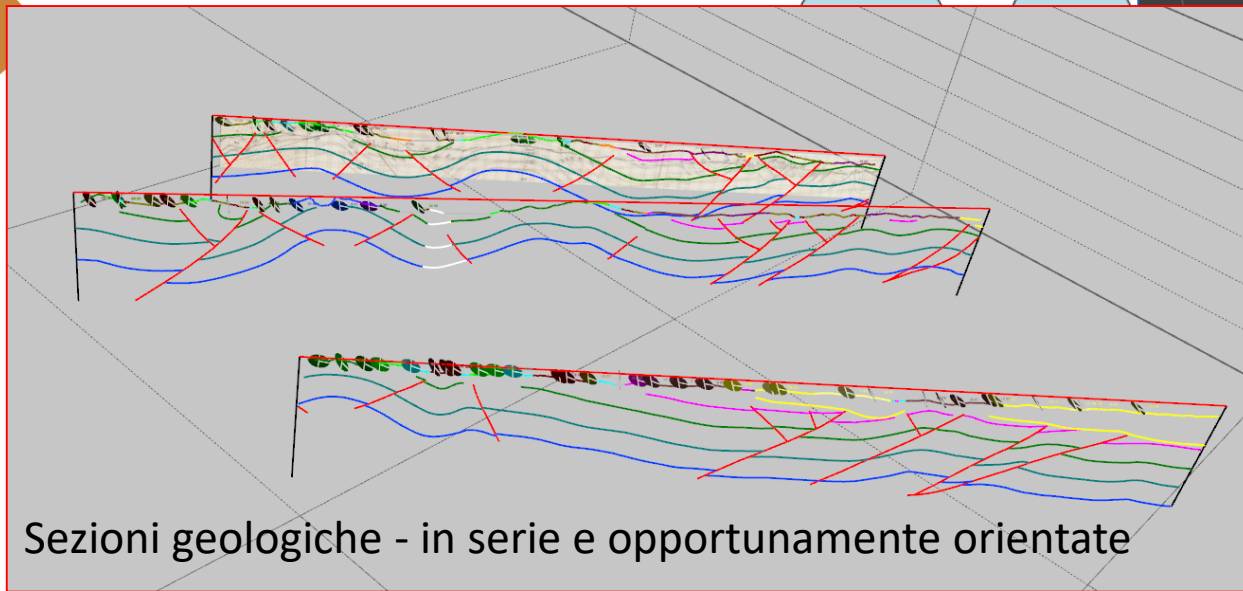


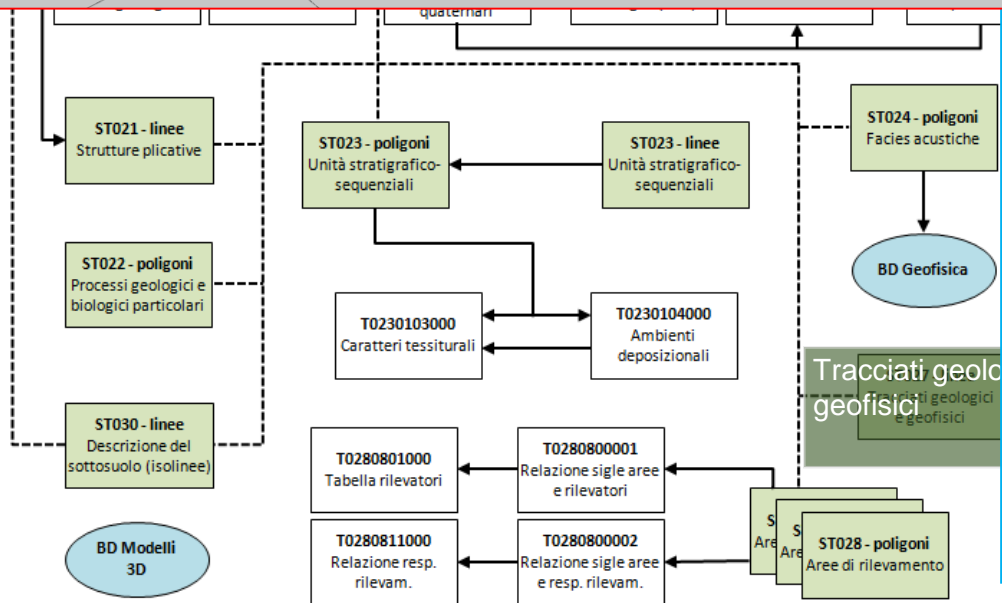
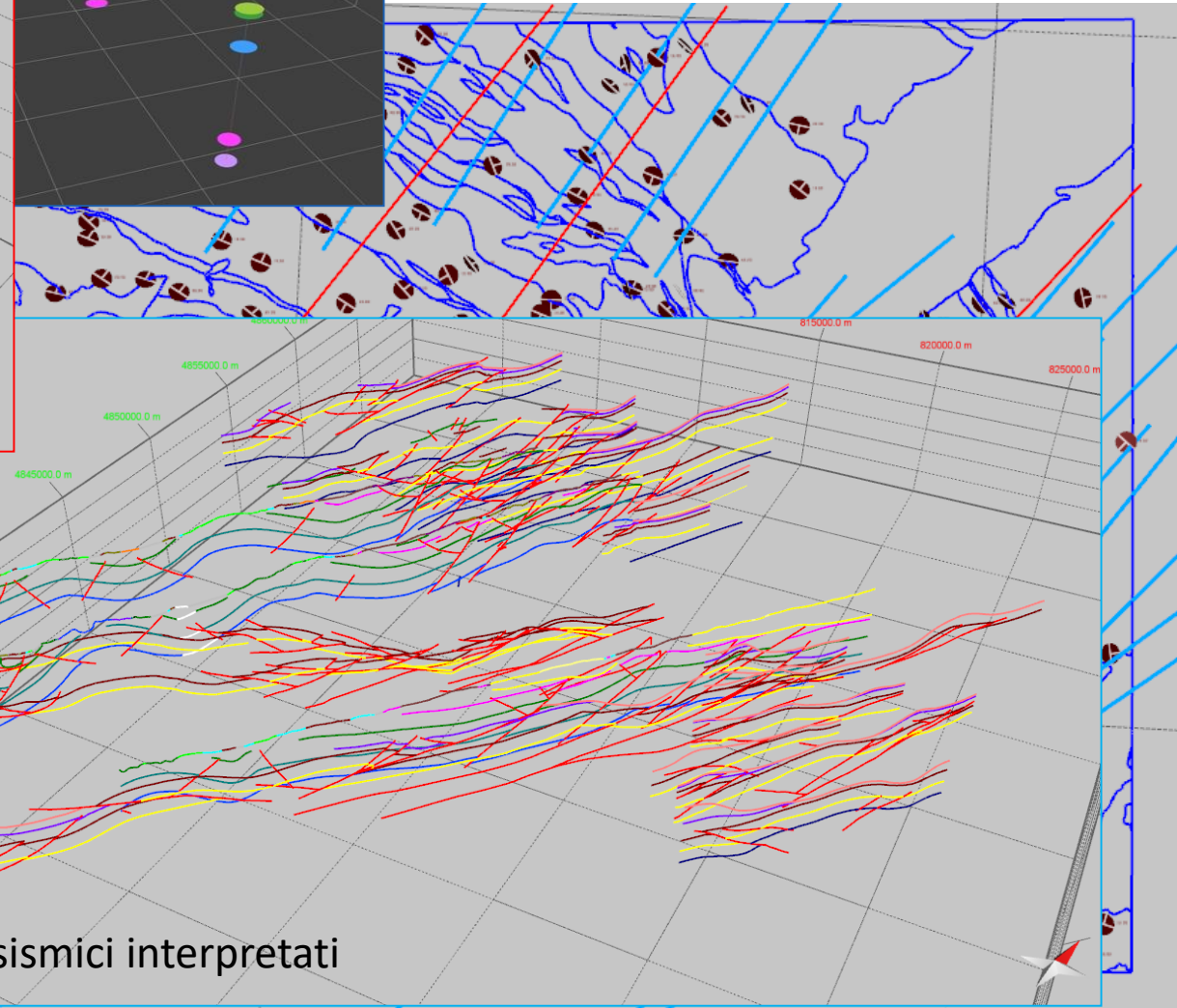
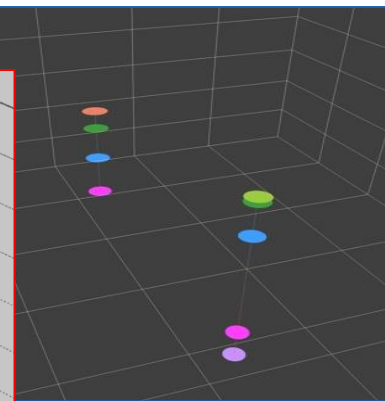
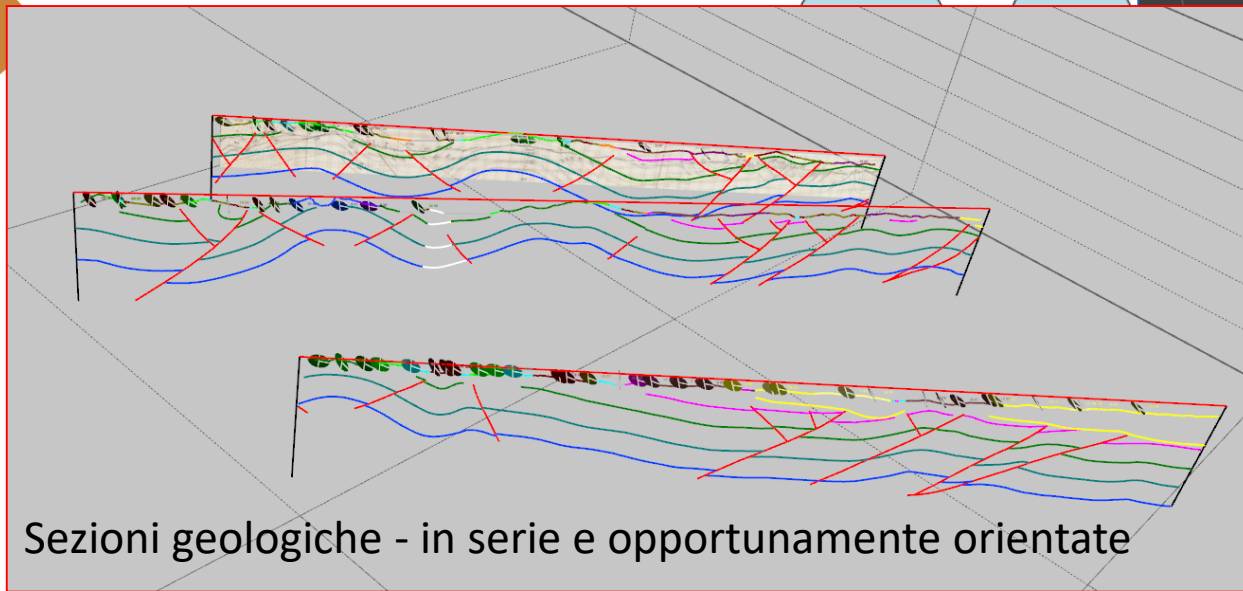


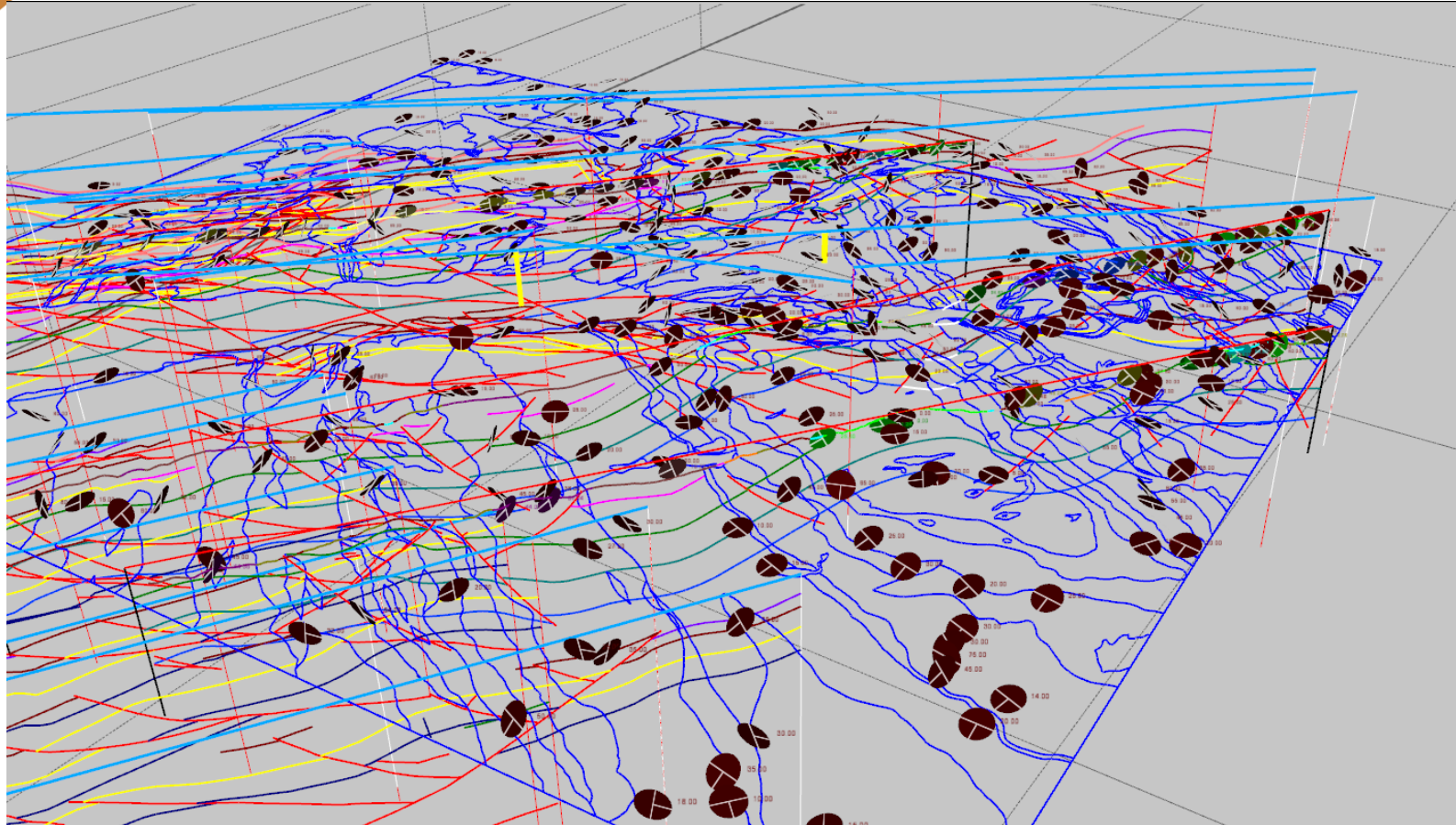


Tracciati geologici e geofisici

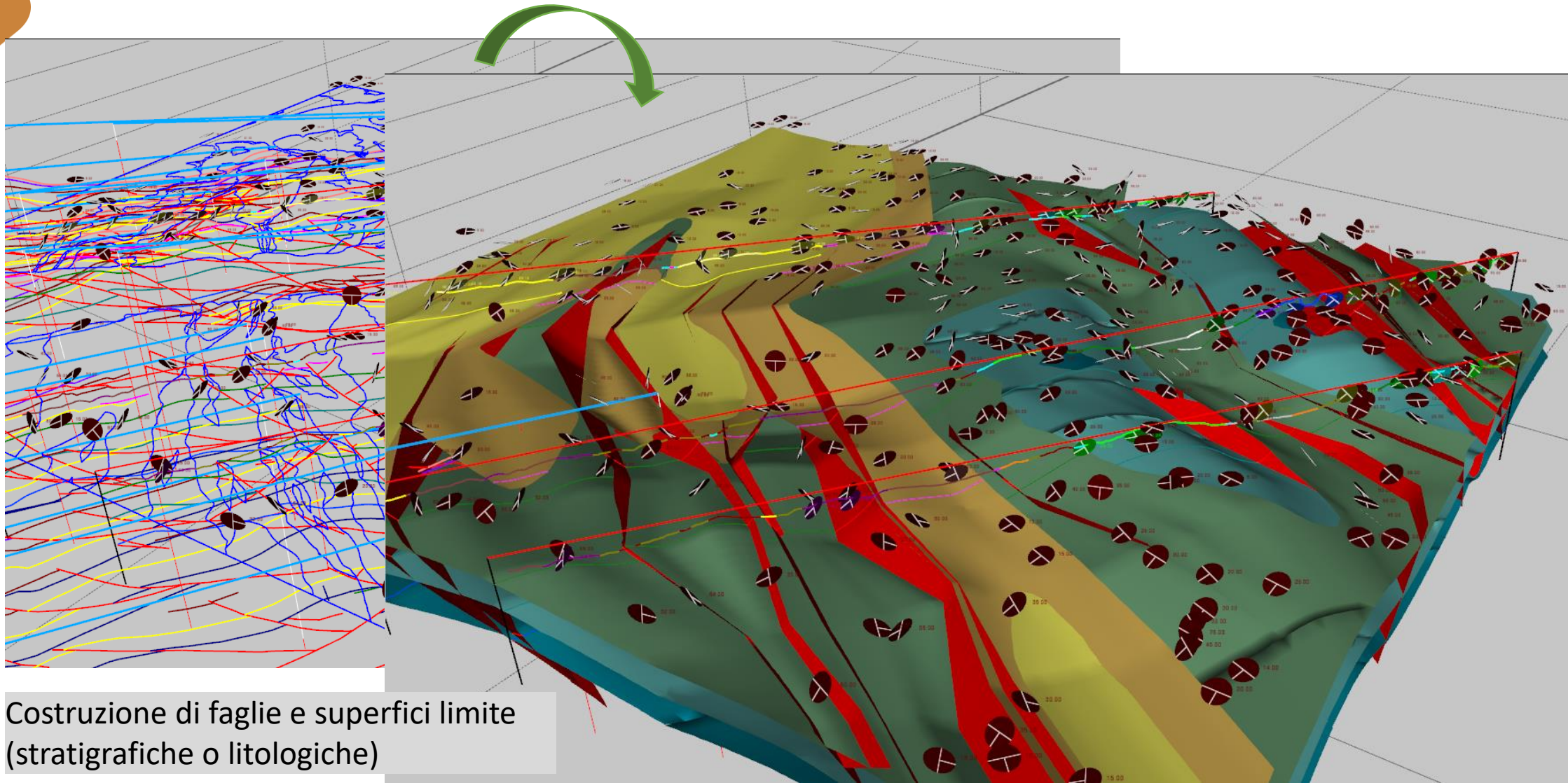


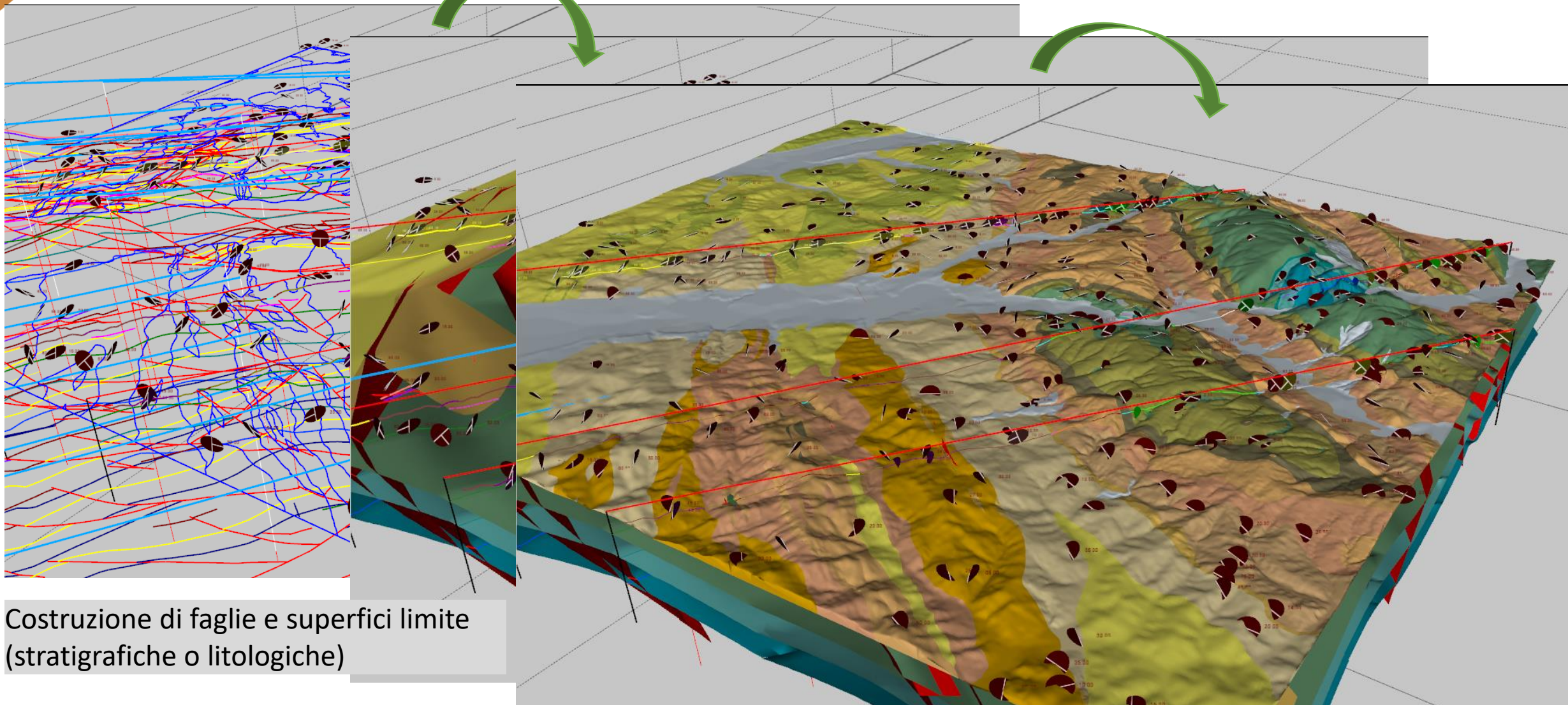


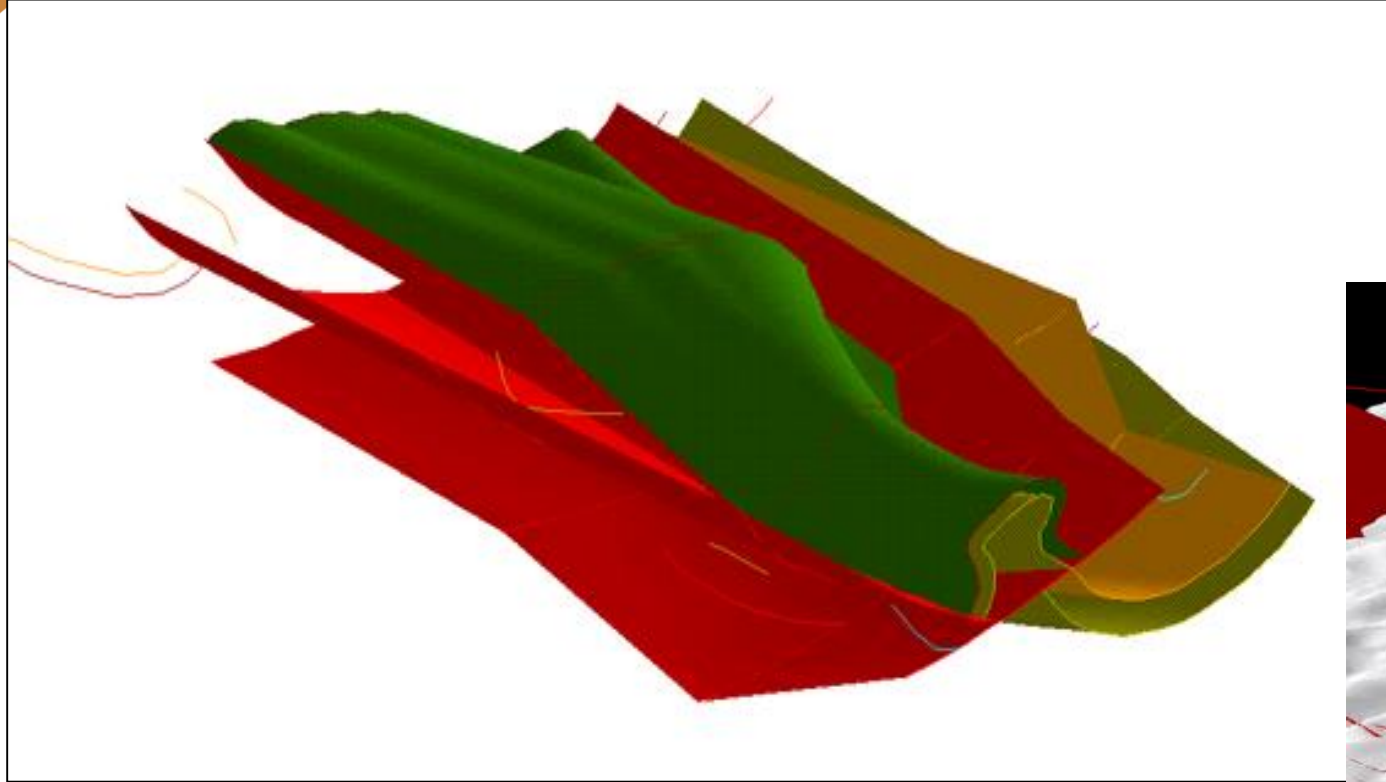




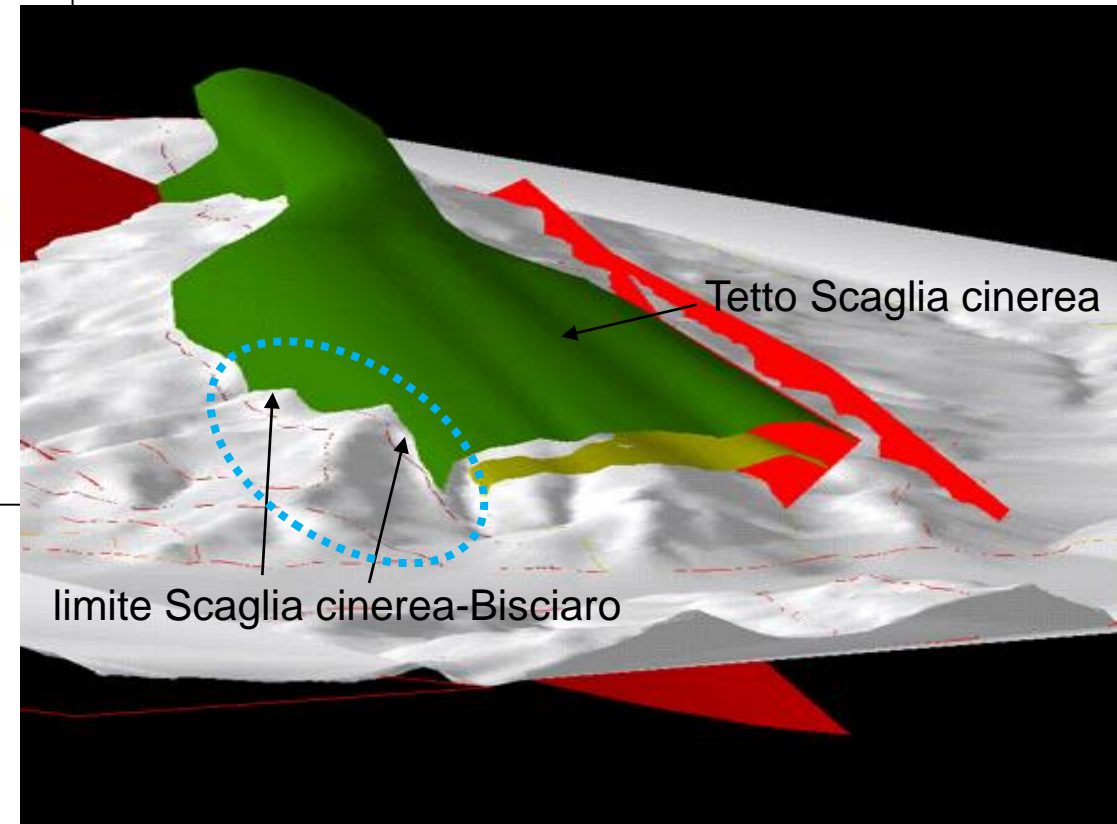
Costruzione di faglie e superfici limite
(stratigrafiche o litologiche)

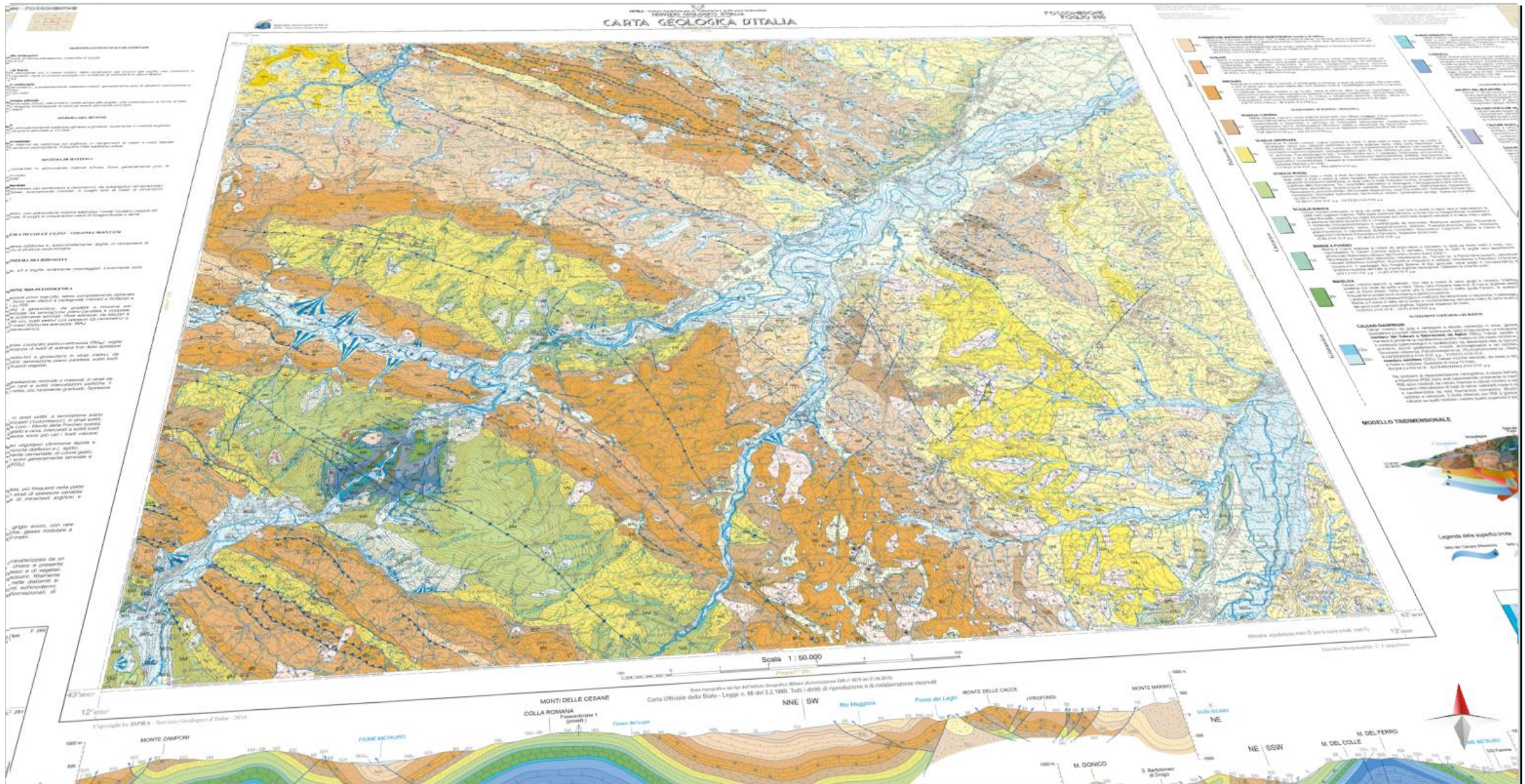






Far procedere la costruzione del modello parallelamente al rilevamento consente di verificare la congruenza geometrica delle strutture e dei limiti cartografati, identificare aree in cui è necessario tornare, modificare ipotesi

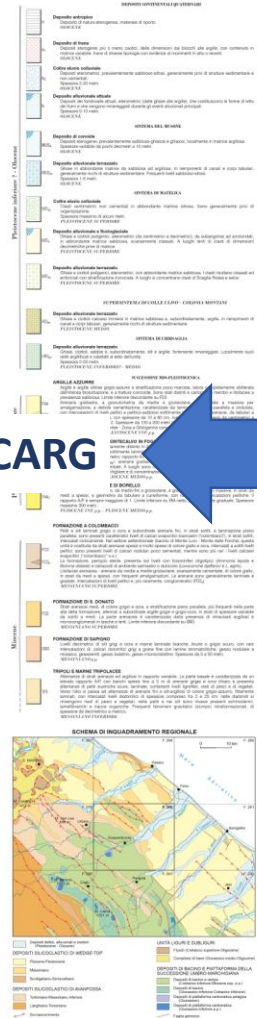
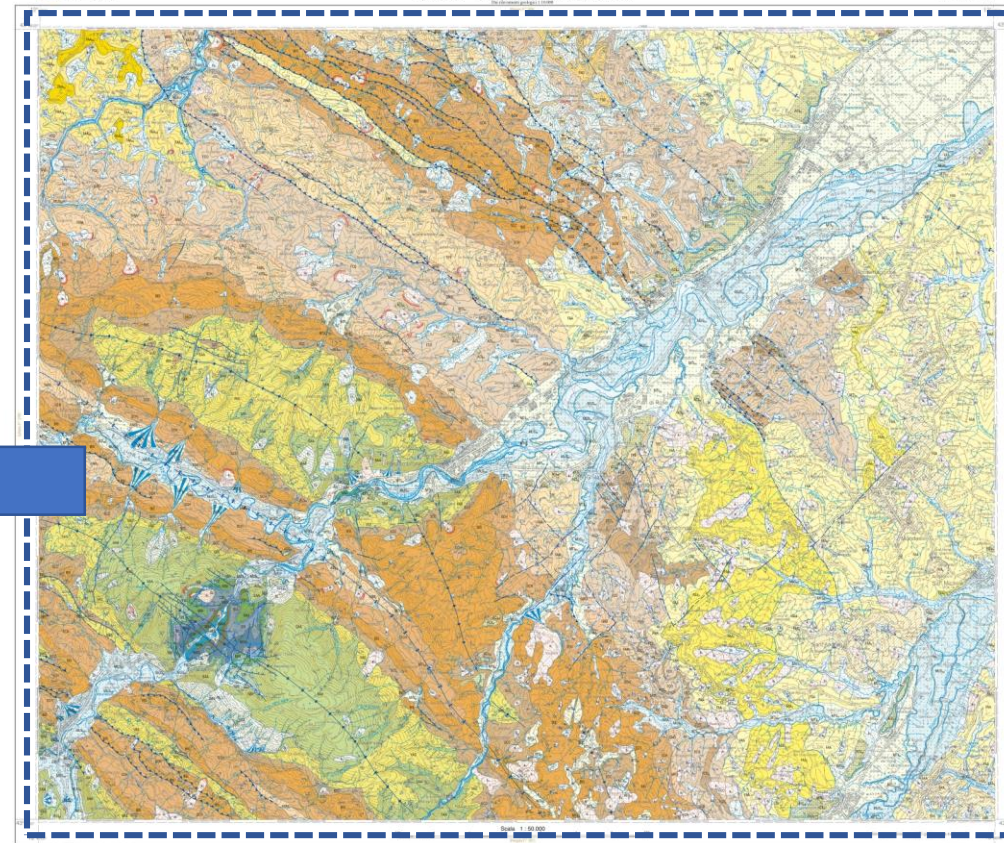




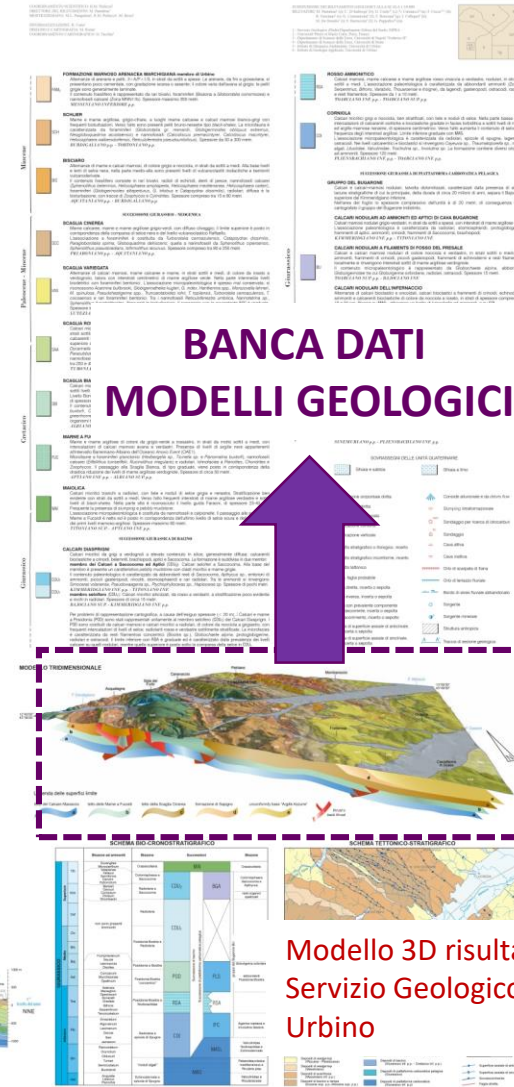


ISPRA - Istituto Superiore per la Protezione e la Ricerca Ambientale
SERVIZIO GEOLOGICO D'ITALIA
CARTA GEOLOGICA D'ITALIA

FOSSOMBRONE
FOLIO 280



BANCA DATI CARG



BANCA DATI
MODELLI GEOLOGICI



Modello 3D risultato della collaborazione tra Servizio Geologico d'Italia e Università di Urbino

- Utilizzo prevalente di dati di sottosuolo (sismica e pozzi)

Integrare dati di superficie (!) con dati di sottosuolo

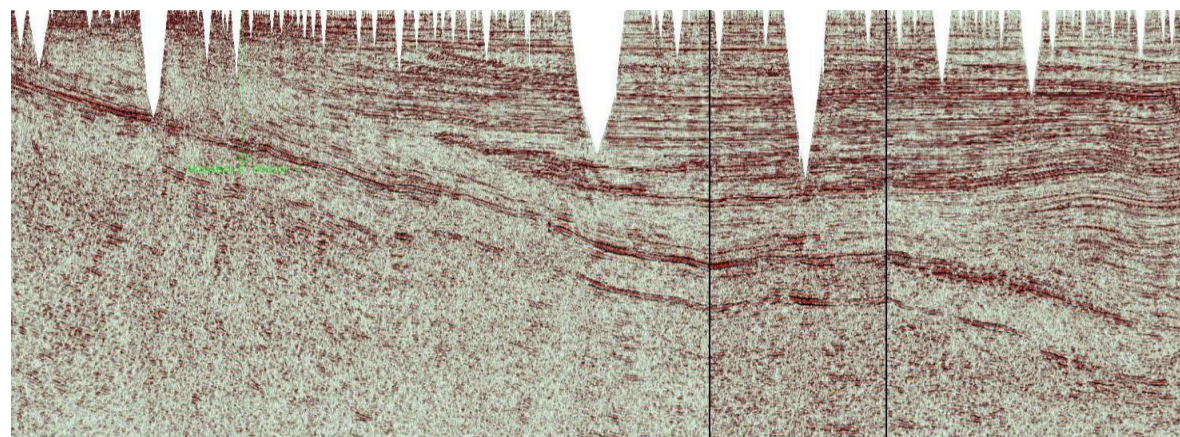
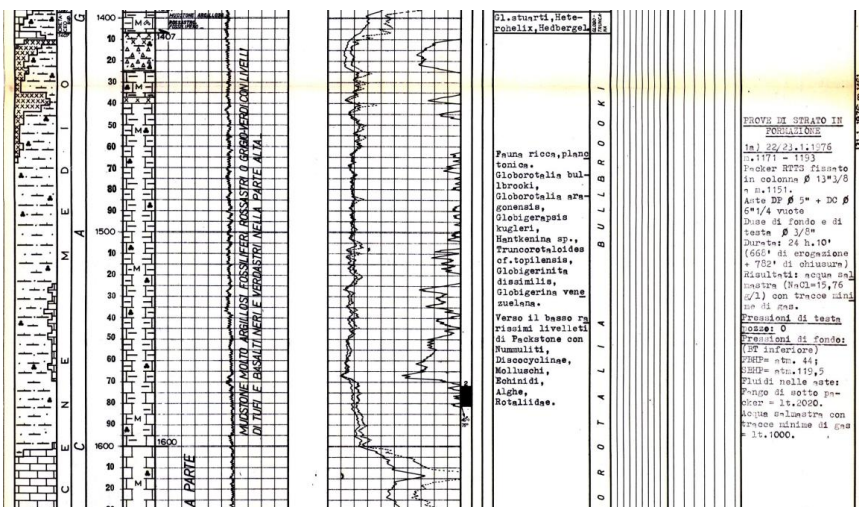


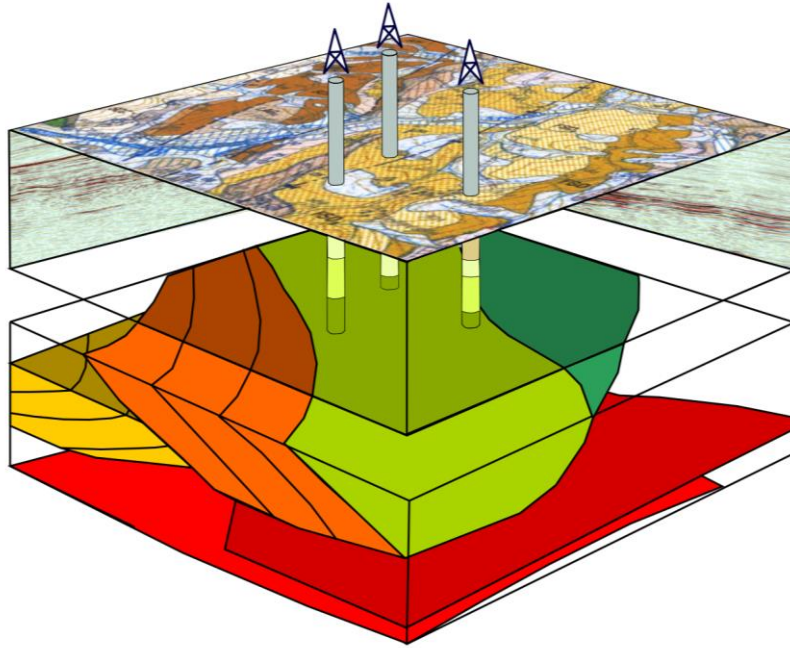
Reperimento dati da banche dati regionali e nazionali

Reperimento dati presso soggetti privati



Per il progetto CARG, il Servizio Geologico d'Italia ha raggiunto un accordo con ENI per accedere i dati di sottosuolo delle aree dei fogli





- Modelli geologici profondi (profondità > 1000 metri)
- Modelli geologici superficiali (profondità max 500-1000 metri)
- Utilizzo di dati provenienti dal rilevamento geologico
- Integrazione di dati di superficie, da rilevamento geologico, e sottosuolo, sismica e pozzi

- **Dati di superficie**

Banca dati CARG
Dati di terreno

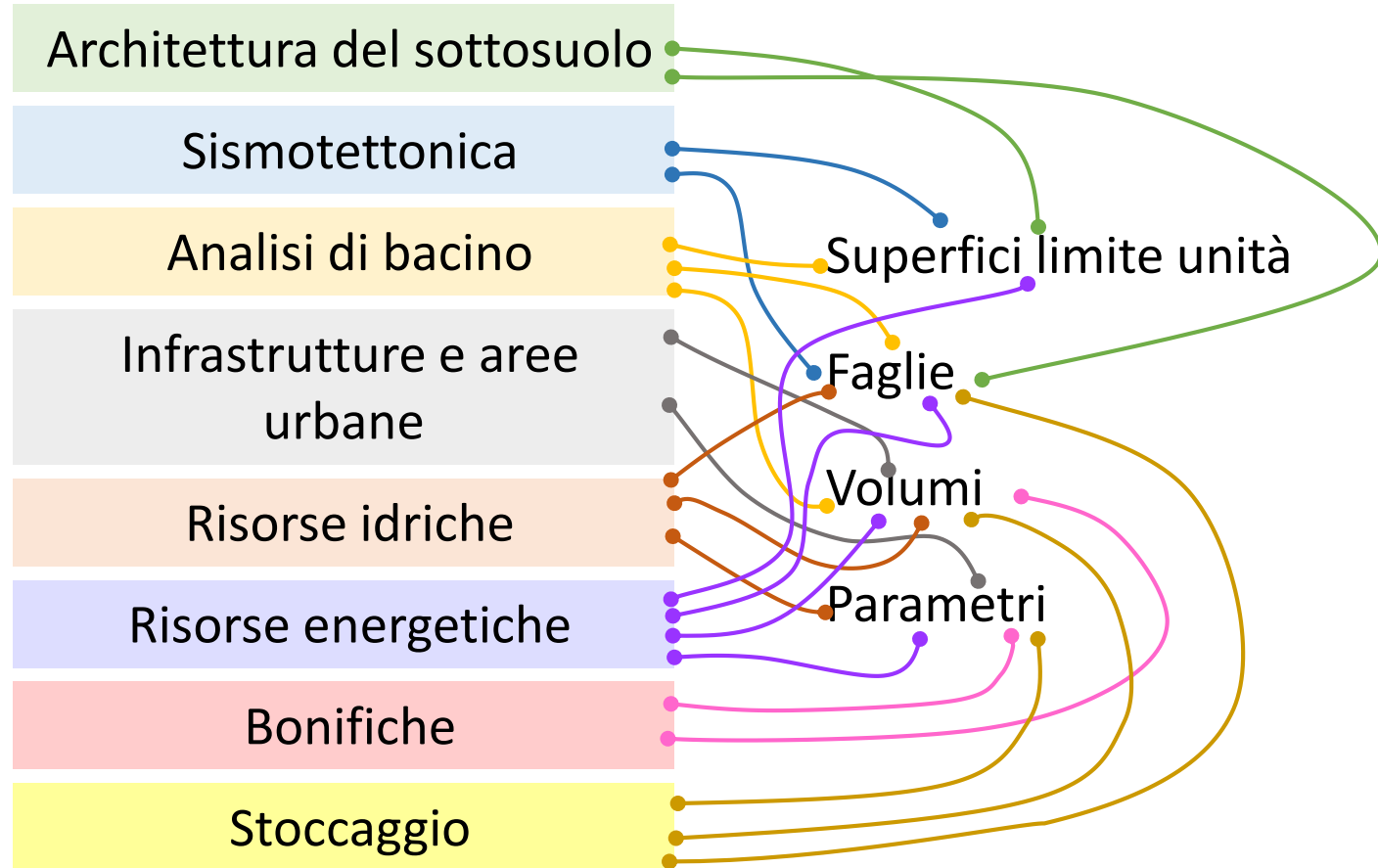
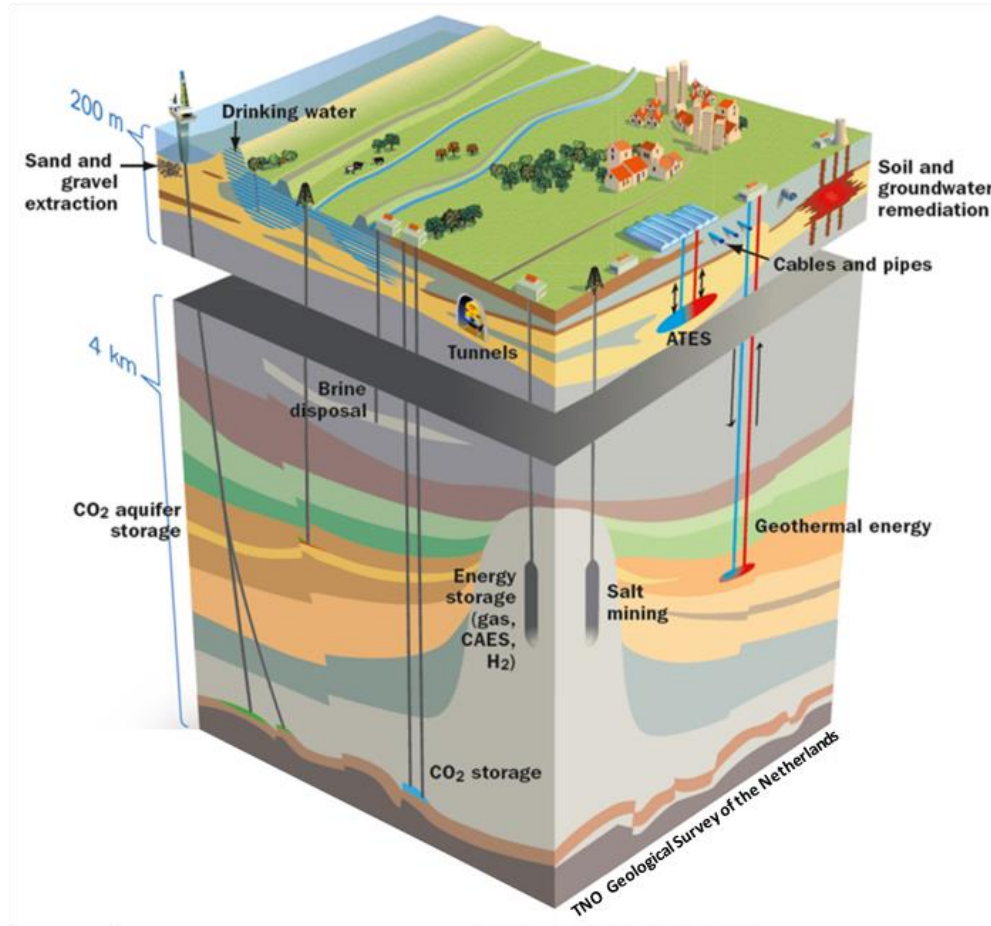
- **Banche dati pubbliche**

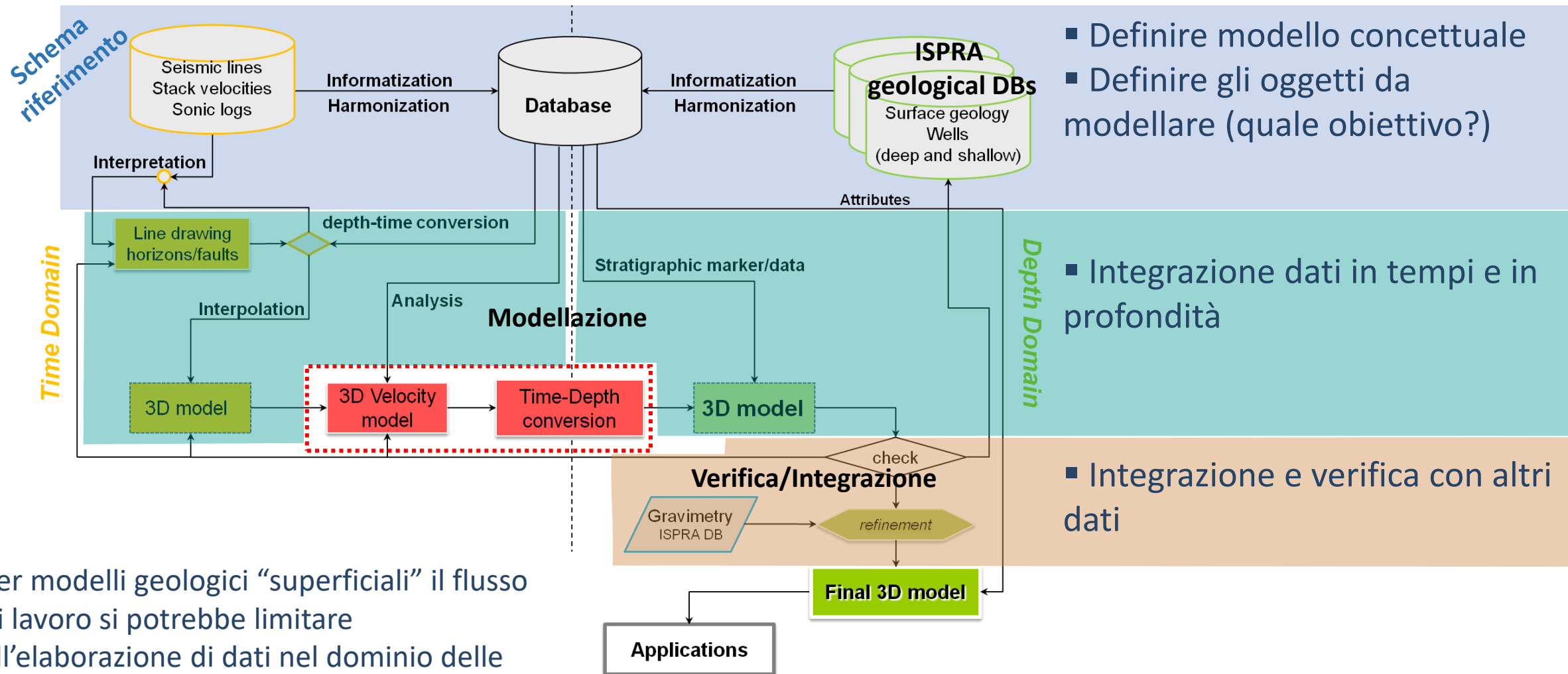
Prove geognostiche
Sondaggi L. 464/84
Sondaggi profondi
Sismica CROP e Videpi
Dati gravimetrici

- **Dati soggetti a riservatezza**

Linee sismiche
Dati di pozzo
Tabelle Tempi/Profondità
Dati gravimetrici

Definire l'obiettivo e i corpi geologici che si vogliono modellare





- Definire modello concettuale
- Definire gli oggetti da modellare (quale obiettivo?)

- Integrazione dati in tempi e in profondità

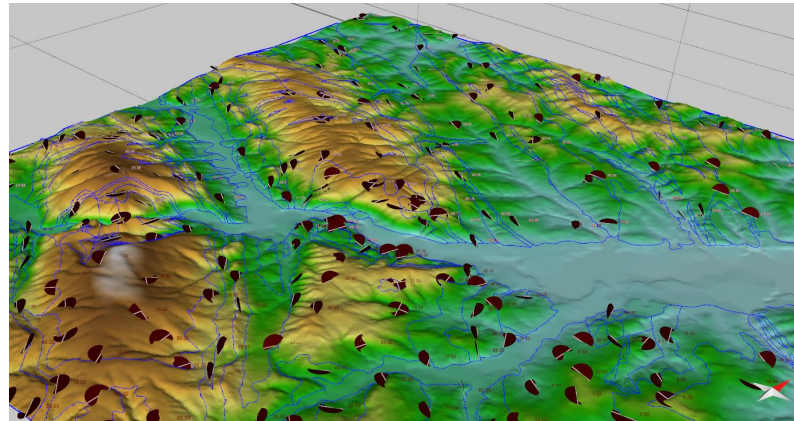
- Integrazione e verifica con altri dati

Per modelli geologici “superficiali” il flusso di lavoro si potrebbe limitare all’elaborazione di dati nel dominio delle profondità

Rapporti ISPRA, 234/2015

✓ ST018 Unità geologiche (linee e poligoni)

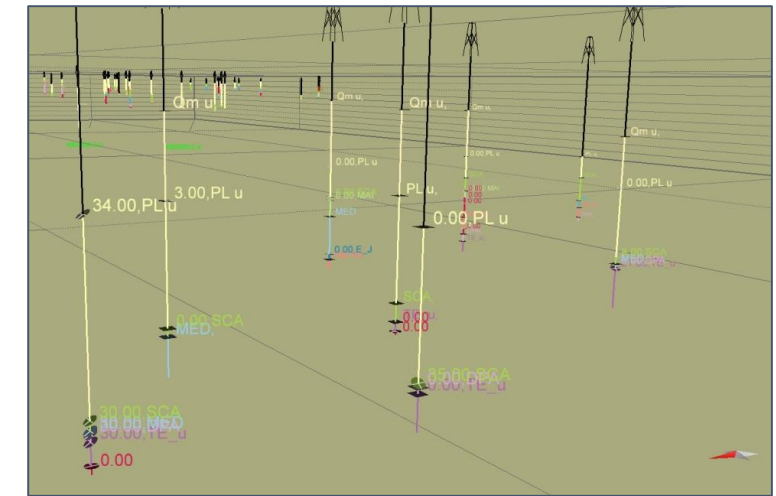
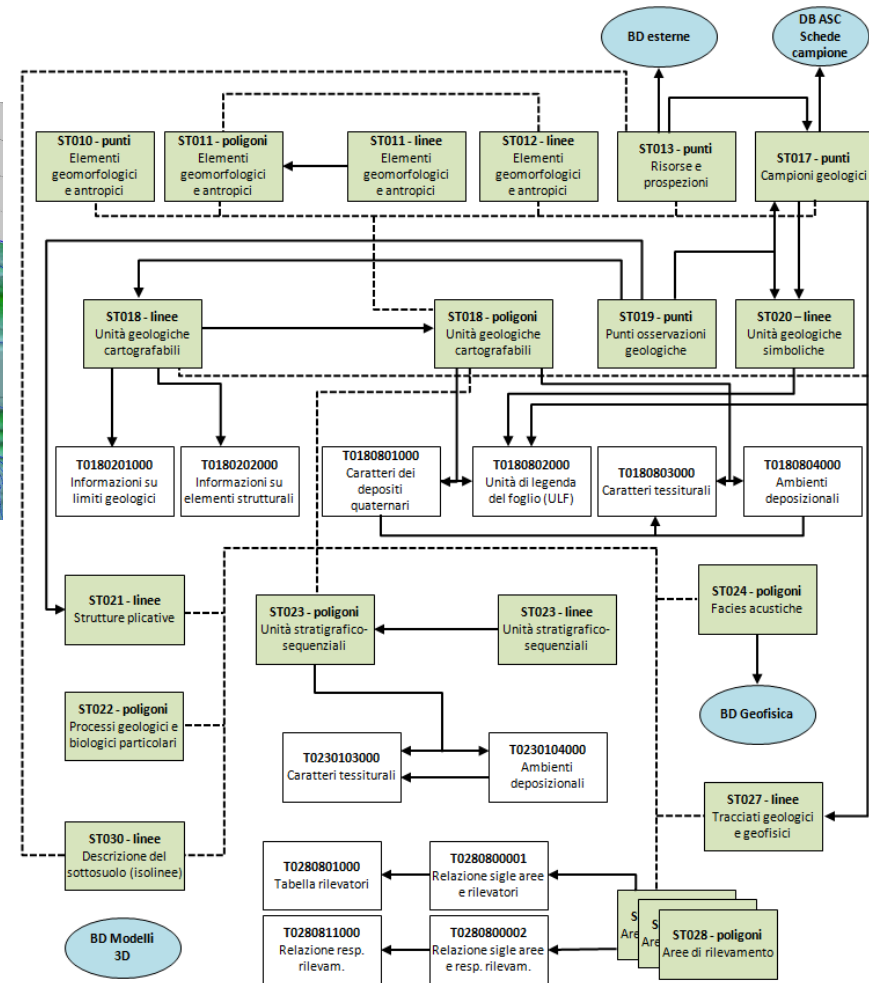
✓ ST019 Osservazioni geologiche (punti)



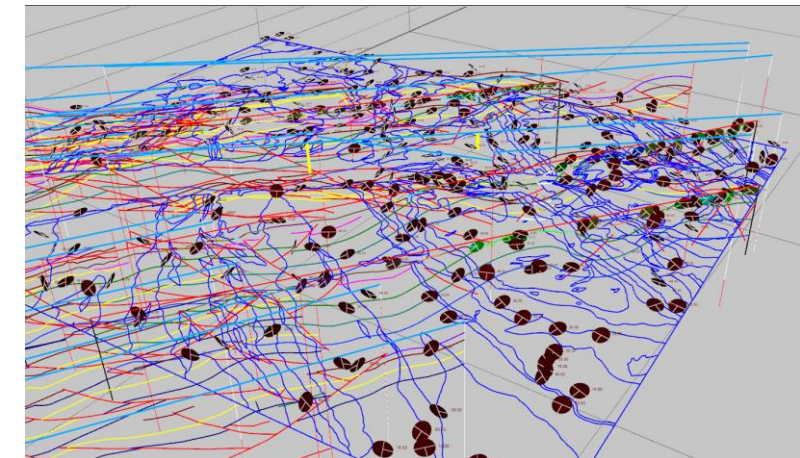
Utilizzo dei dati come
strutturati in banca dati



Garantiamo interoperabilità tra
carta geologica e modello 3D

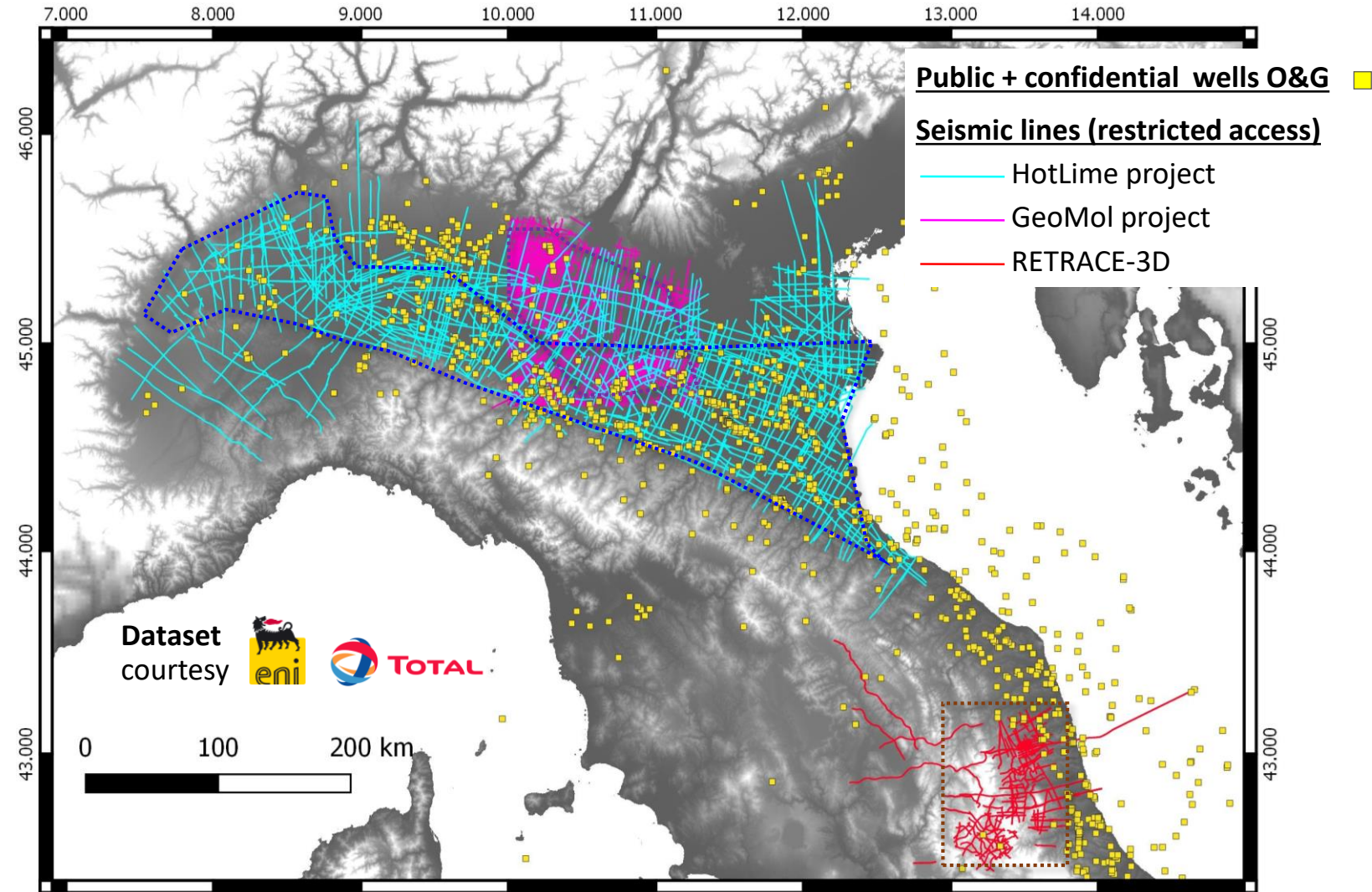
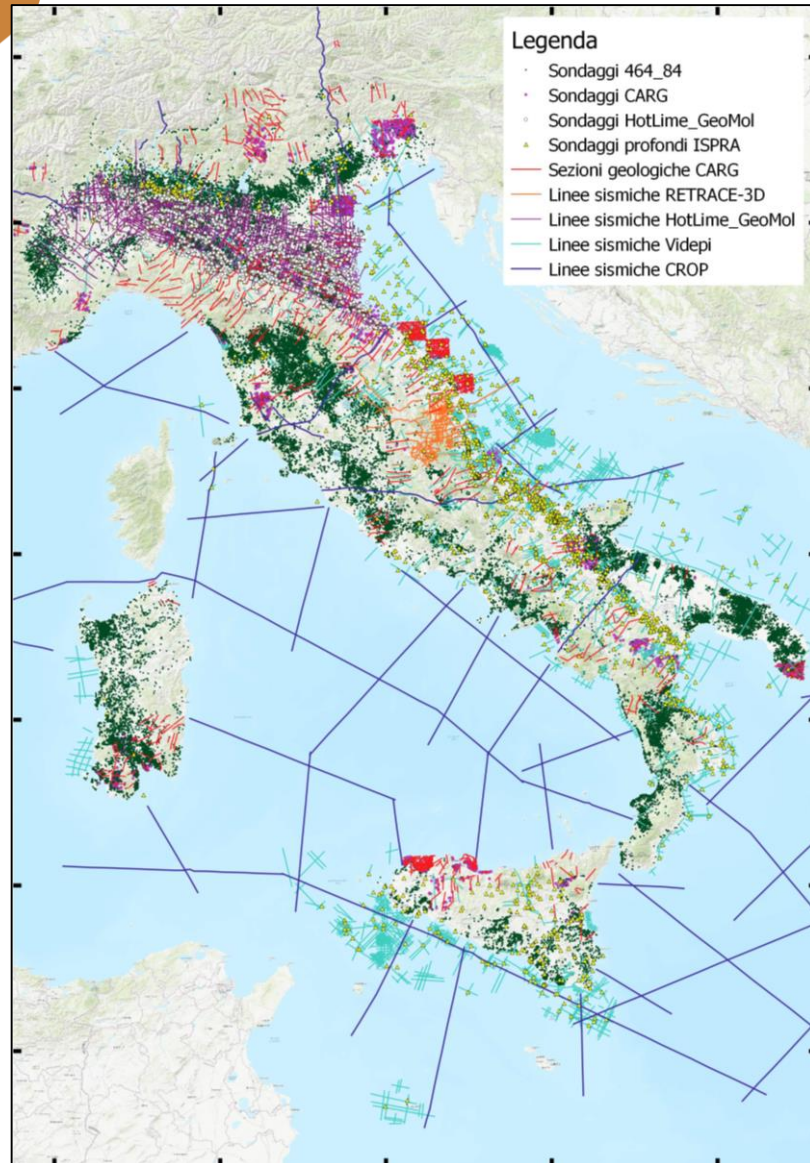


✓ ST013 Risorse e prospezioni



✓ ST027 Tracciati geologici e geofisici

MODELLAZIONE GEOLOGICA 3D: METODOLOGIA



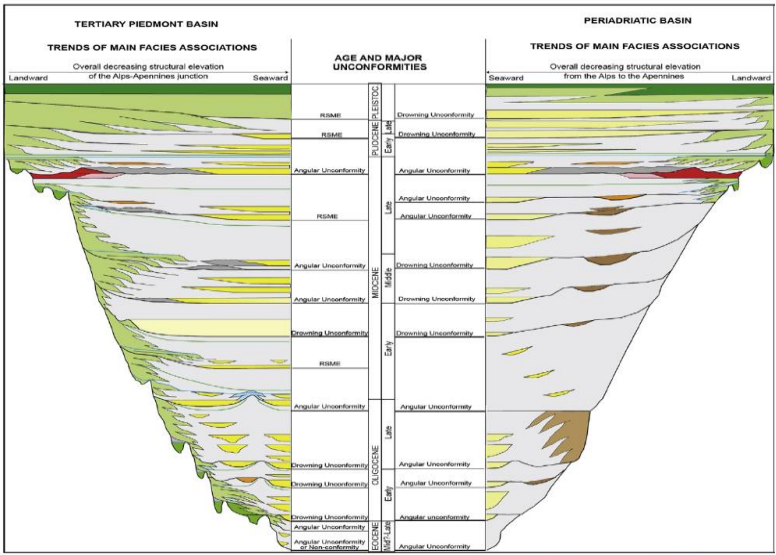
GeoMol
Assessing subsurface potentials of the Alpine Foreland Basins
for sustainable planning and use of natural resources

HotLime
GeoERA

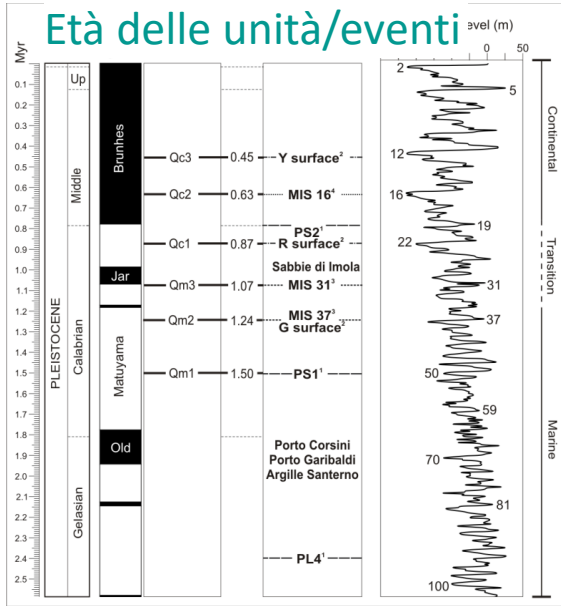
HIKE
GeoERA
GEO-ENERGY

RETRACE-3D
centRAL Italy EarThquakes interATED Crustal model

Cosa modellare – quale utilizzo



Rapporti tra unità
Rossi, MPG, 2017



Maesano & D'Ambrogi, IJG, 2016

11 unconformities

4 formation tops

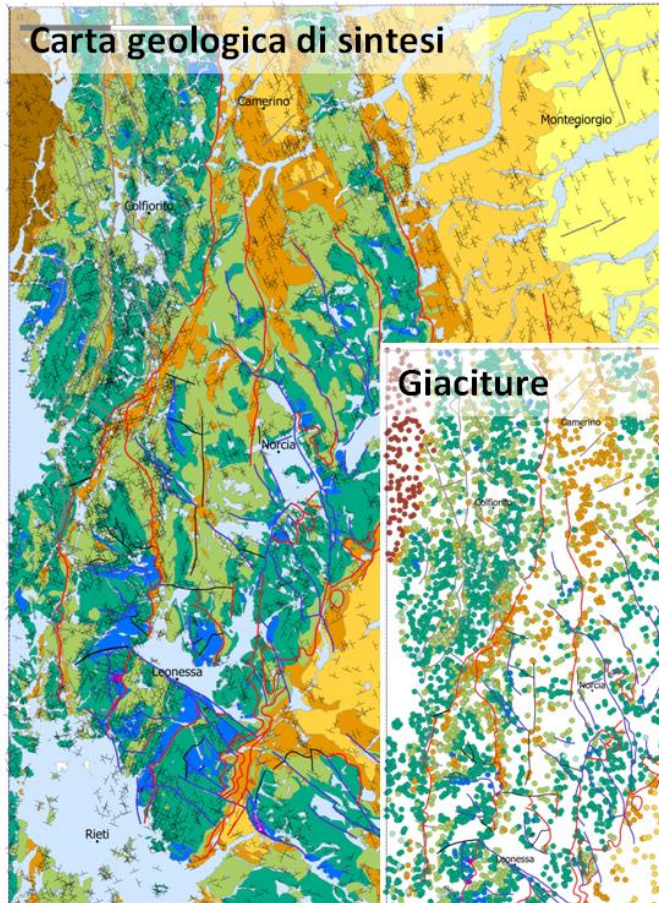
	UNIT NAME	HORIZON NAME
Pleistocene	PLCc	QC3
	PLCb	QC2
	PLCa	QC1
	PLMd	QM3
	PLMc	QM2
	PLMb	QM1
Pliocene	PLMa	GEL
	PL	PL
Upper Miocene	MESb	ME3
	MESa	ME1
Lower Miocene	MIO	MLW
	EO-OL	SCA
Early Cret	K-PAL	MAI
	J-K	NOR
Late Triassic	TR-J	TE
	P-TR	

- Differenze litologiche → MZS, risorse idriche, subsidenza
- Unità stratigrafiche → Target per risorse
- Orizzonti (top/unconformity) → Analisi bacino e tettonica
- Orizzonti pleistocenici → Tettonica attiva
- Livelli di scollamento → Sismotettonica

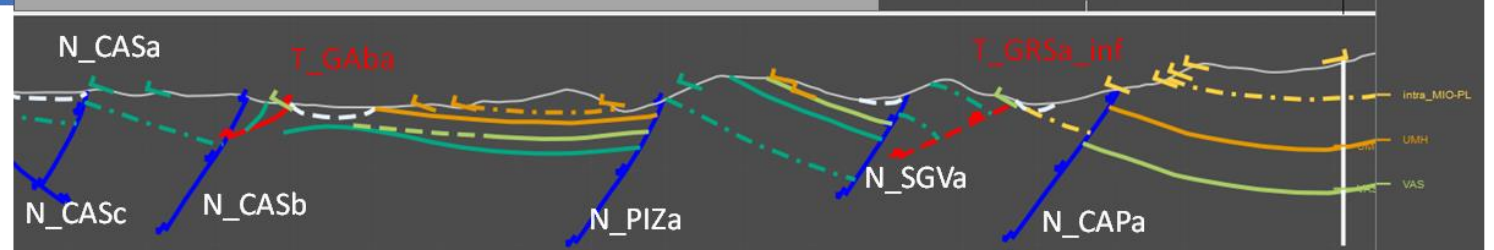


Schema di riferimento

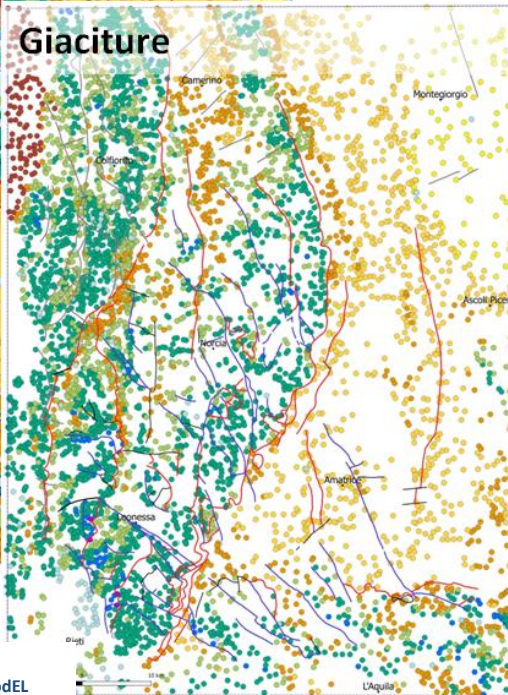
Rapporti ISPRA, 234/2015



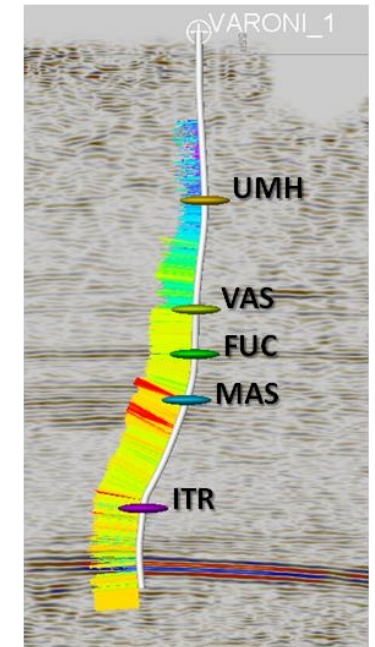
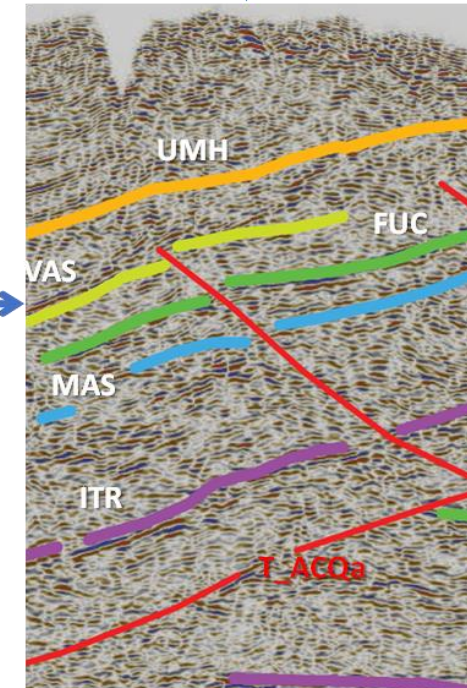
Sezione geologica da carta geologica di sintesi



Giaciture

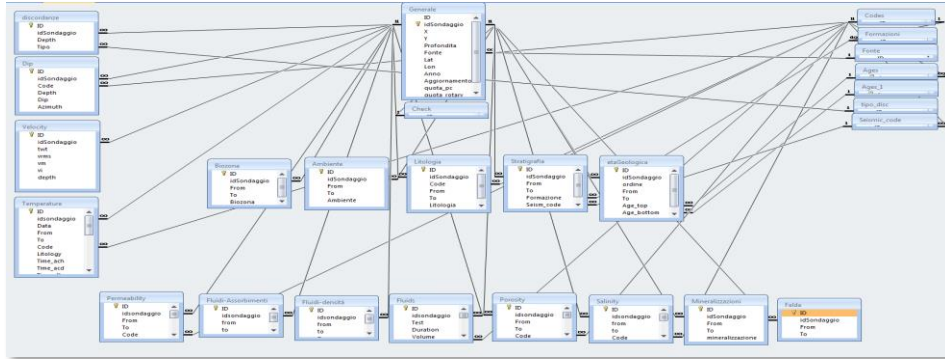


Unit code (Geo_3D)	Formations (Unit_Geo3D/ NOME_ULF)	HORIZON code
MIO-PL	Laga	UMH
EO-MIO	Marne a Pteropodi	VAS
	Marne con Cerrognia	
	Bisciaro	
	Scaglia Cinerea (SCC)	
C-EO	Scaglia (B+R+V)	FUC
J-C	Marne a Fucoidi (FUC)	MAS
	Maiolica	
	Diaspri/Filaments	
	Marne M. te Serrone (RSN)	
	Corniola	
J	Calcere Massiccio	ITR
TR	Dolomie/Evaponti	BAS
	Basamento	



RETRACE-3D
central Italy EarthQuakes interATED Crustal model

Banche dati sondaggi nazionali/regionali



Banche dati dedicate

Assessing subsurface potentials of the Alpine Foreland Basins for sustainable planning and use of natural resources

Alpine

GeoMol Italian Pilot Area

Well log database

Tables

[General](#)
[Stratigraphy](#)
[Age](#)
[Lithology](#)
[Enviroment](#)
[Biozones](#)
[Dip/Azimuth](#)
[Unconformities](#)

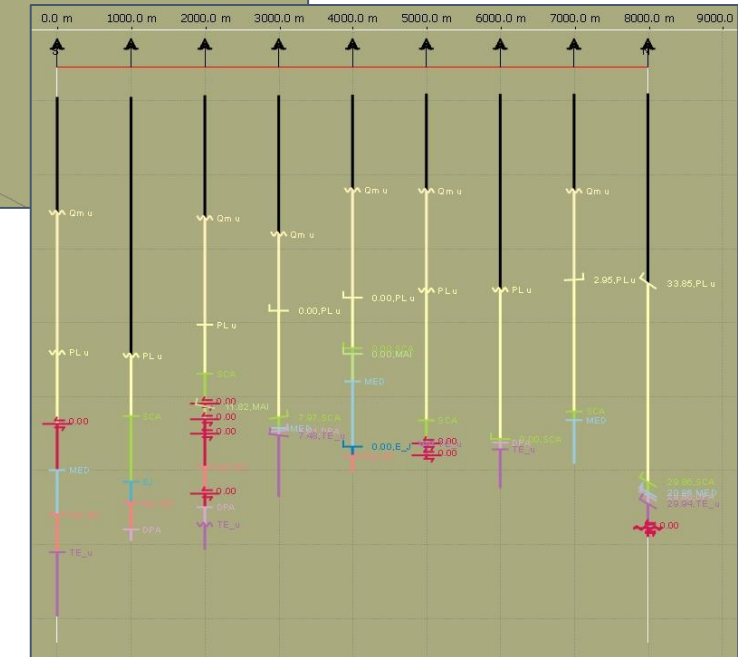
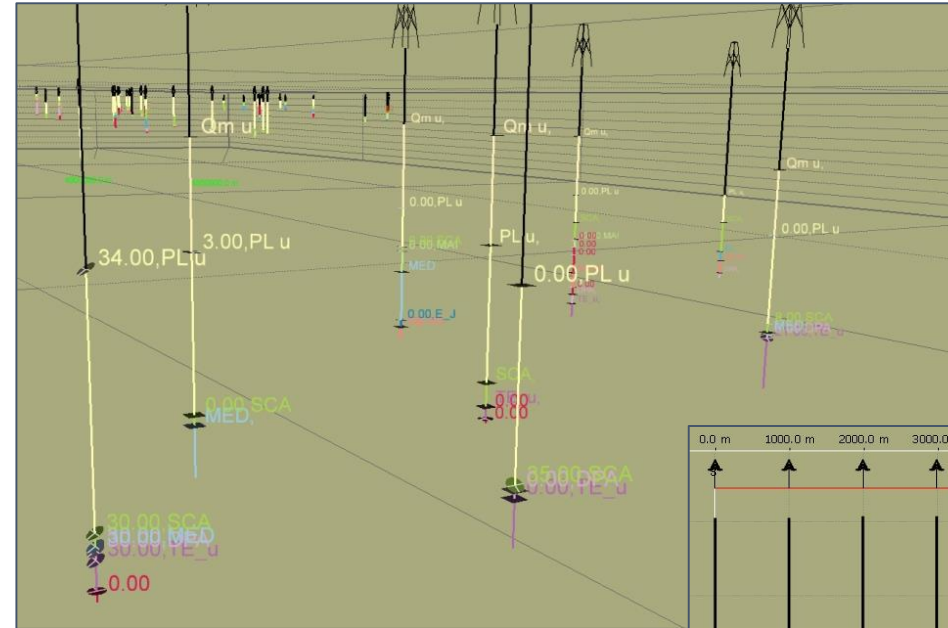
[Velocity](#)
[Mineralizations](#)
[Temperatures](#)
[Porosity](#)
[Permeability](#)
[Salinity](#)
[Fluids](#)
[Groundwater](#)

Query

[Interroga codice formazione](#)

[Interroga stratigrafia sondaggio](#)

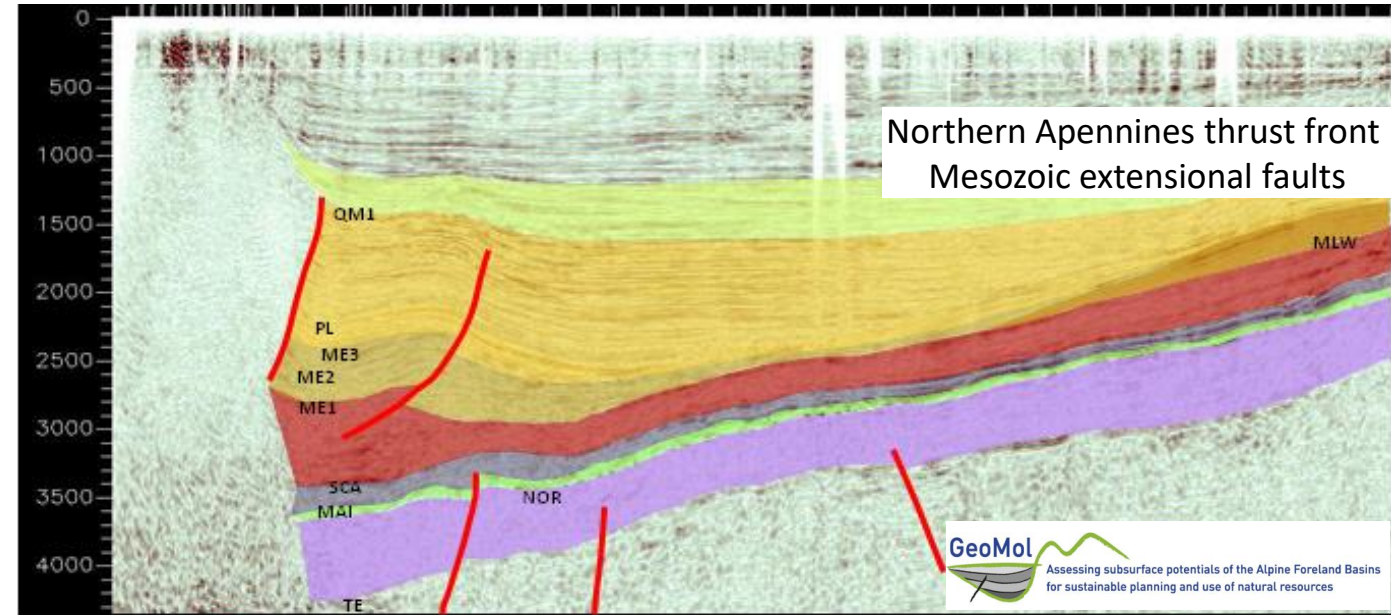
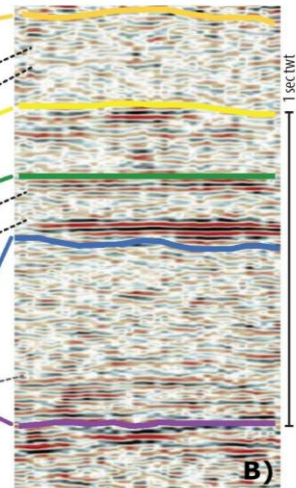
[Primary keys](#)



Q	cont. deposits	
PL	Plio-Pleist deposits	
MIO	Laga	
EO-MIO	Marne a Pteropodi	UMH
	Marne con Cerrogna	
	Bisciaro	
	Scaglia Cinerea	VAS
C-EO	Scaglia successione (Bianca-Rossa Variegata)	FUC
	Marne a Fucoidi	
J-C	Malolica	
	Diaspri/Filaments	
	Marne M.te Serrone	
	Corniola	MAS
J	Calcare Massiccio	
TR	Dolostones	BUR
	Evaporites	ITR
	pre-Upper Triassic	PUT

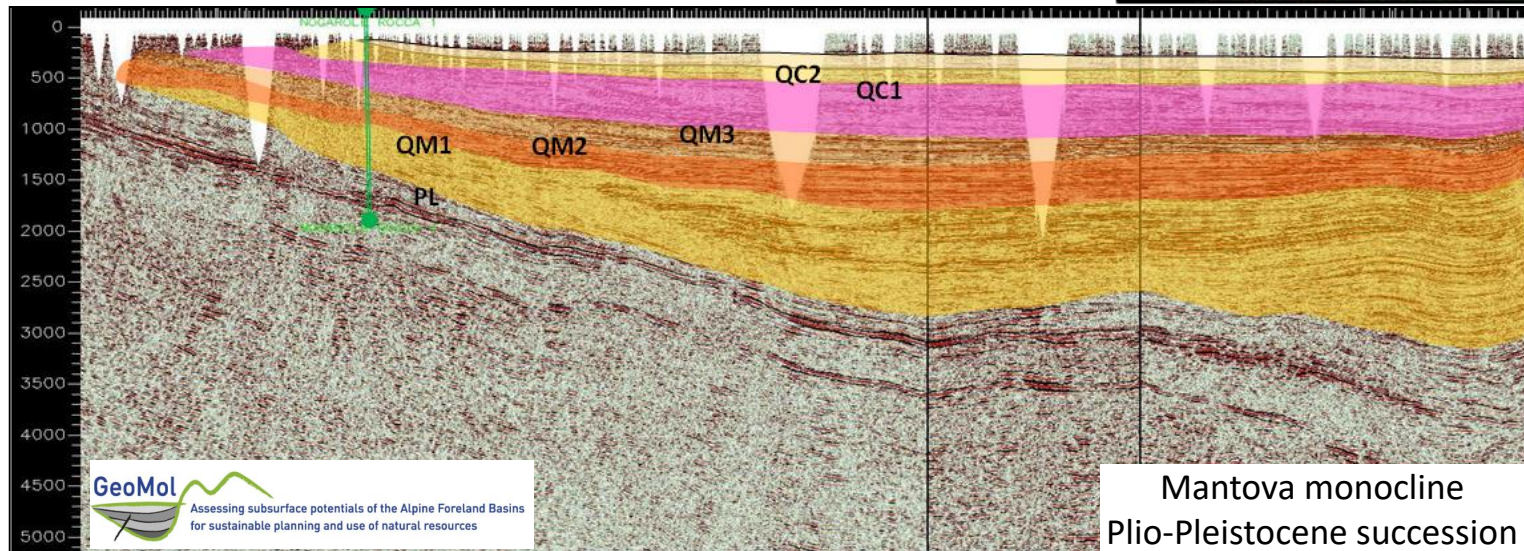


RETRACE-3D
centRal Italy EarThquakes interATED Crustal model

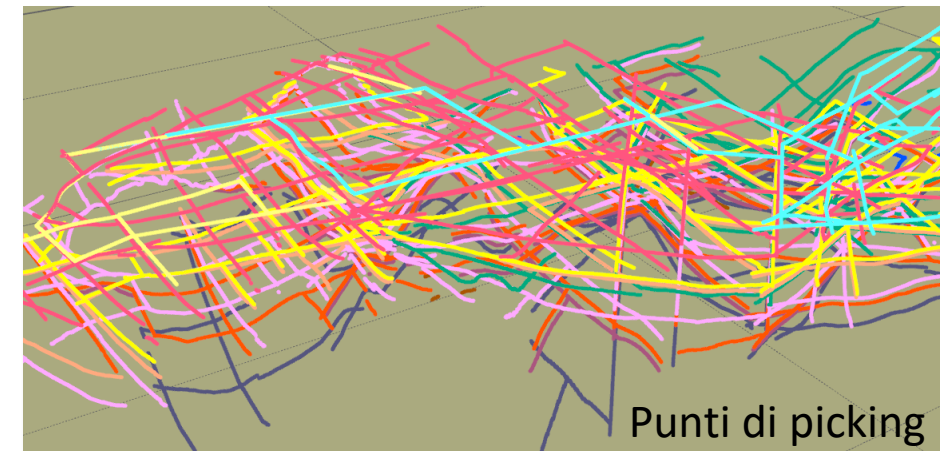


GeoMol

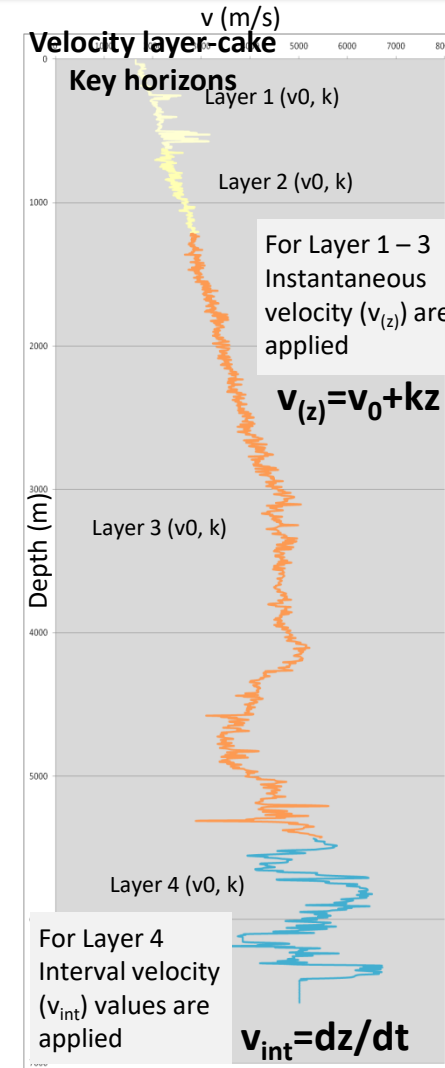
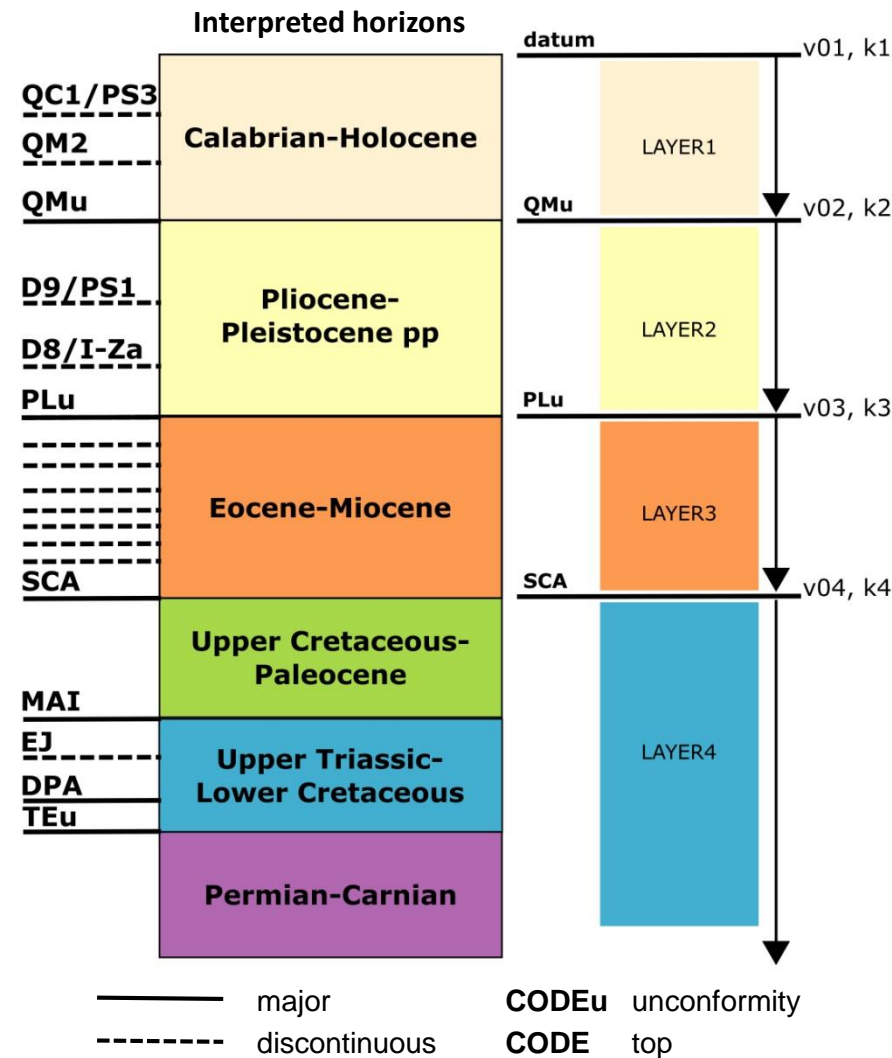
Assessing subsurface potentials of the Alpine Foreland Basins for sustainable planning and use of natural resources



Mantova monocline
Plio-Pleistocene succession



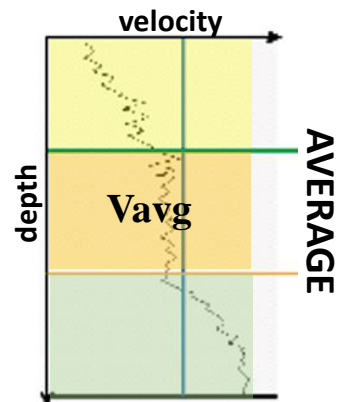
Punti di picking



L'integrazione dei dati in tempi con i dati in Profondità richiede la conversione Tempi/Profondità

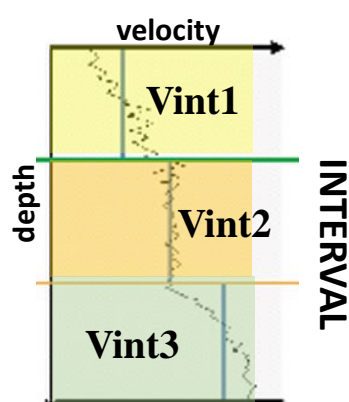
- assetto geologico
- estensione dell'area da modellare
- finalità del modello

MODELLO
DI VELOCITÀ

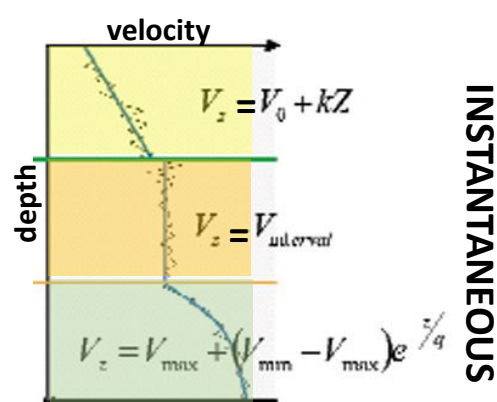


is the velocity
from surface
 $V_{avg} = Z/t$

Etris et al. 2002



is the average velocity
of a given interval, with
V constant within the
interval
 $V_{int} = dZ/dt$

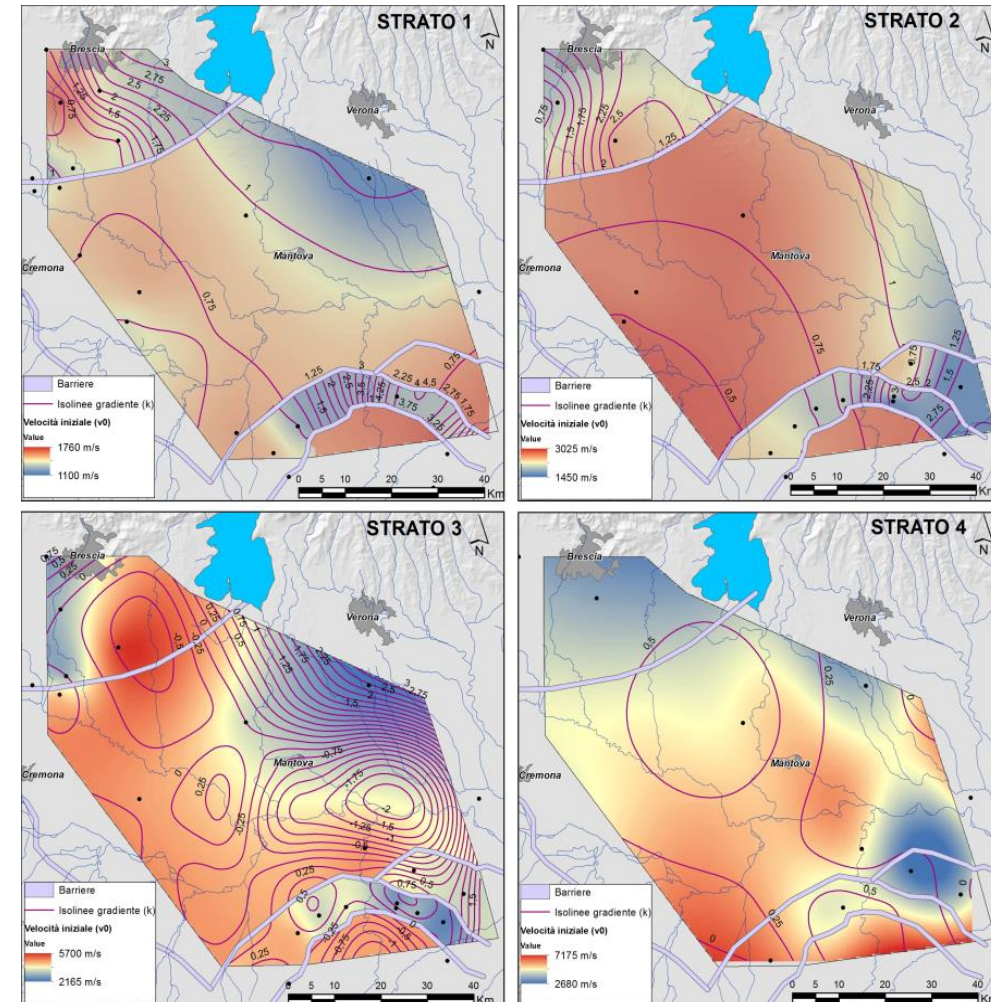


is the velocity at a specific
point at depth Z within a given
interval. Over this interval the
Vinst changes in relation to a
gradient K

$$V_{inst} = V_0 + Kz$$

allows to consider the velocity
variation with depth

Mappe V0 e k



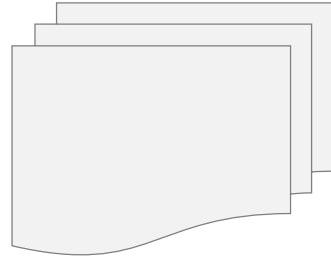
Maesano & D'Ambrogio, Comp & Geosc, 2017

Schema strat riferim

Q	Calabrian-Holocene	Layer 1
PL	Pliocene-Pleistocene pp	Layer 2
EO-MIO	Eocene-Miocene	Layer 3
K-PAL	Upper Cretaceous-Paleocene	Layer 4
TR-K	Upper Triassic-Lower Cretaceous	
P-TR	Permian-Carnian	

Velocity layer-cake

Dati letteratura
Stacking velocity
Tabelle Time-Depth

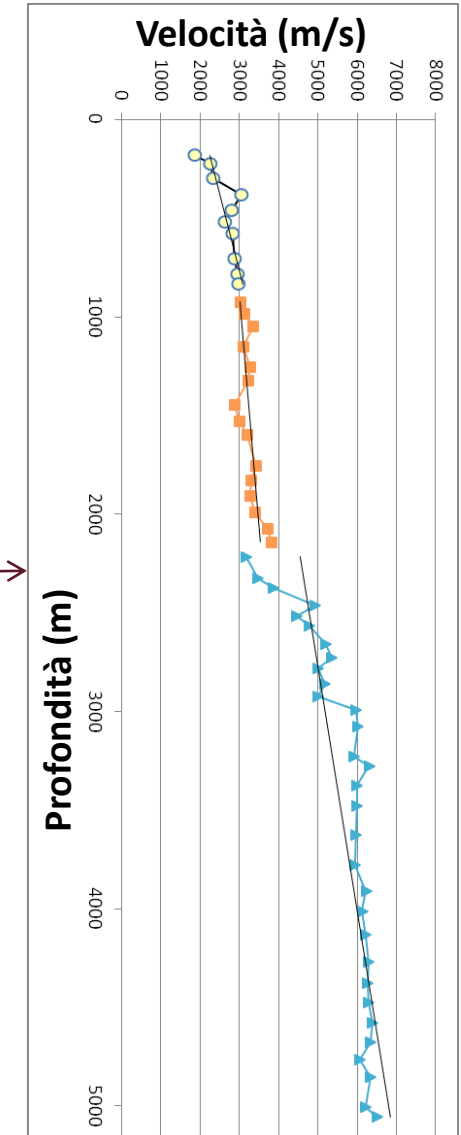


From	To	Formazione	Code	Age_top	Age_bottom
0	130	Alluvioni	HOL	Holocene	Holocene
130	857	Argille del Santerno	PL	Zanclean	Zanclean
857	2093	Gessoso Solifera	ME	Messinian	Messinian
2093	2210	Marne di Gallare	GAL	Lower Miocene	Lower Miocene
2210	2860	Scaglia	SCA	Rupelian	Turonian
2860	2897	Marne del Cerro	Ku	Upper Cretaceous	Upper Cretaceous
2897	3070	Brecce di Cavone	KI	Albian	Aptian
3070	3145	Rosso Ammonitico	Ju	Malm	Malm
3145	3495	Calcari a Posidonia alpina	Jm	Dogger	Upper Lias
3495	4775	Calcari di Noriglio	Jl	Middle Lias	Lower Lias

Banca dati pozzi



Depth	tw	v
181	194	1865
226	233	2273
300	297	2334
381	350	3047
460	406	2817
517	449	2644
576	491	2824
703	579	2874
784	634	2945
834	668	2978
926	728	3040
987	767	3137
1050	805	3350
1151	870	3102
1255	933	3271
1326	977	3238
1447	1061	2891
1532	1118	2997
1598	1159	3208
1758	1255	3422
1827	1297	3301
1906	1345	3282
1989	1394	3393
2076	1441	3726
2143	1476	3822
2217	1522	3166
2324	1584	3476
2376	1611	3871
2461	1645	4935
2518	1671	4460
2567	1691	4779
2660	1727	5210
2726	1752	5367
2783	1774	5015
2862	1805	5177
2926	1830	5016
2993	1853	5983
3076	1880	6024
3226	1931	5934
3376	1947	5308



Vel-IO 3D – tool per la costruzione di un modello 3D di velocità istantanea

Computers & Geosciences 99 (2017) 171–182

Contents lists available at ScienceDirect

Computers & Geosciences

journal homepage: www.elsevier.com/locate/cageo



Research paper

Vel-IO 3D: A tool for 3D velocity model construction, optimization and time-depth conversion in 3D geological modeling workflow

Francesco E. Maesano^{a,*}, Chiara D'Ambrogio^b

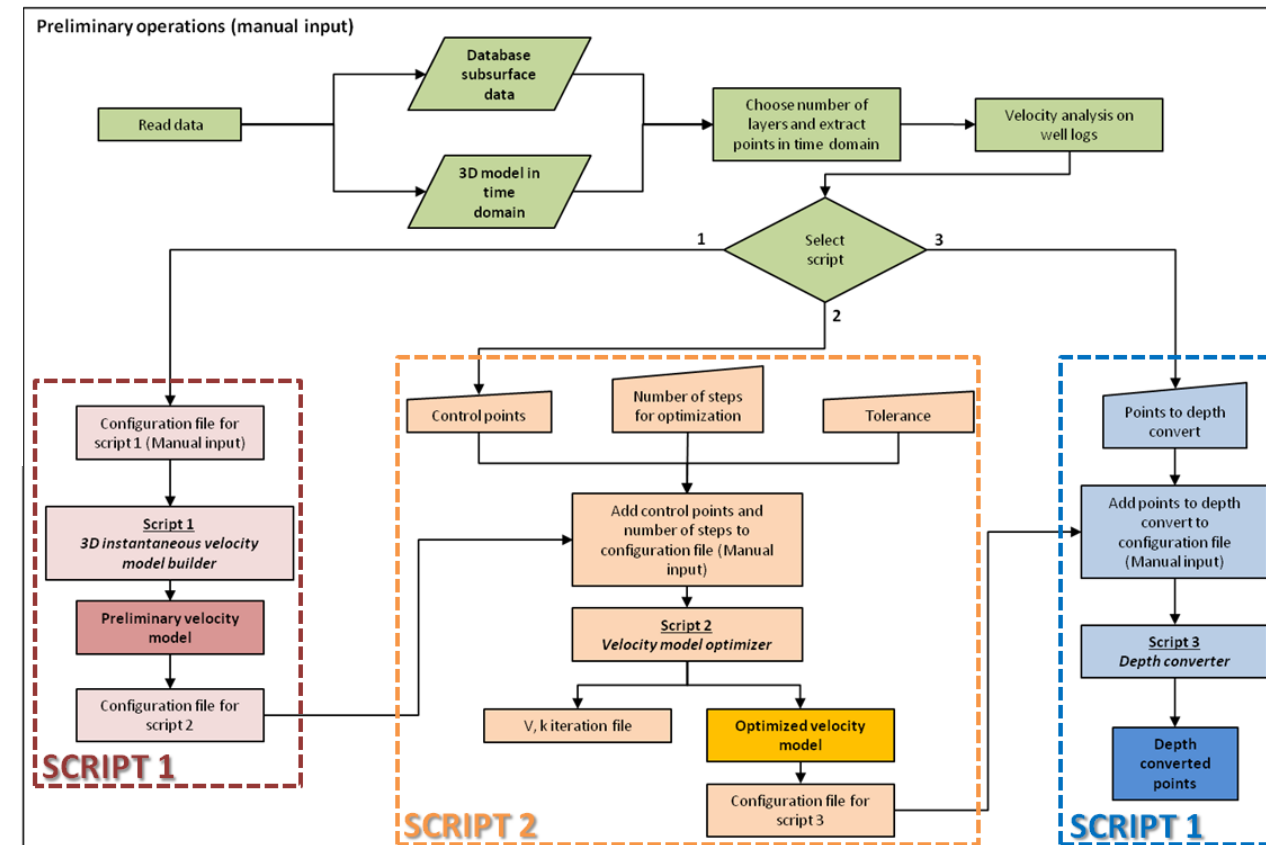
^a INGV – Istituto Nazionale di Geofisica e Vulcanologia, Via di Vigna Murata 605, 00143

^b ISPRA – Servizio Geologico d'Italia, Via Vitaliano Brancati 48, 00144 Rome Italy



Vel-IO 3D è composto da tre script – realizzati in Python 2.7.11 – in grado di automatizzare:


1. Costruzione del modello 3D di velocità istantanea,
2. Ottimizzazione del modello di velocità,
3. Conversione tempi-profondità

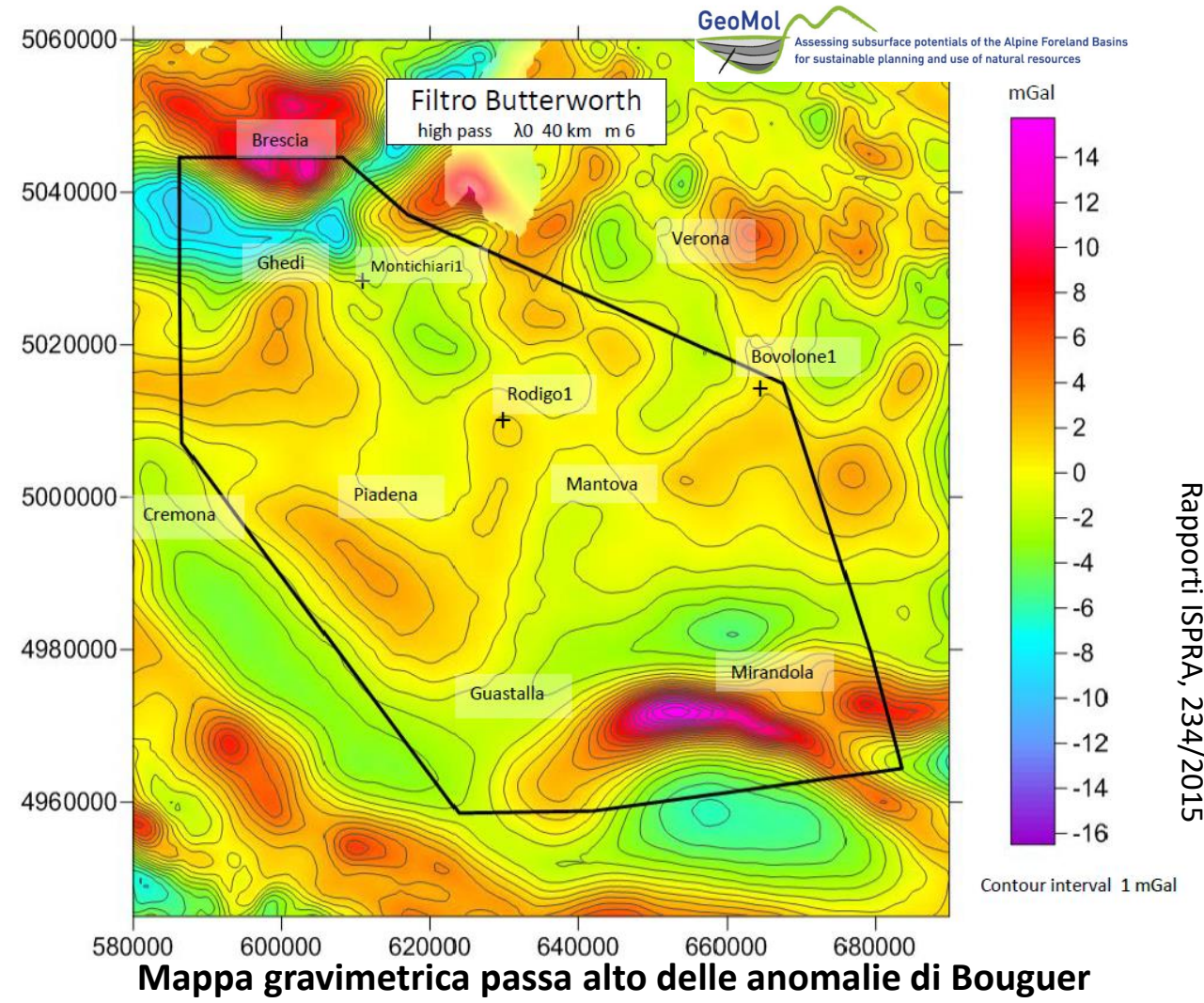
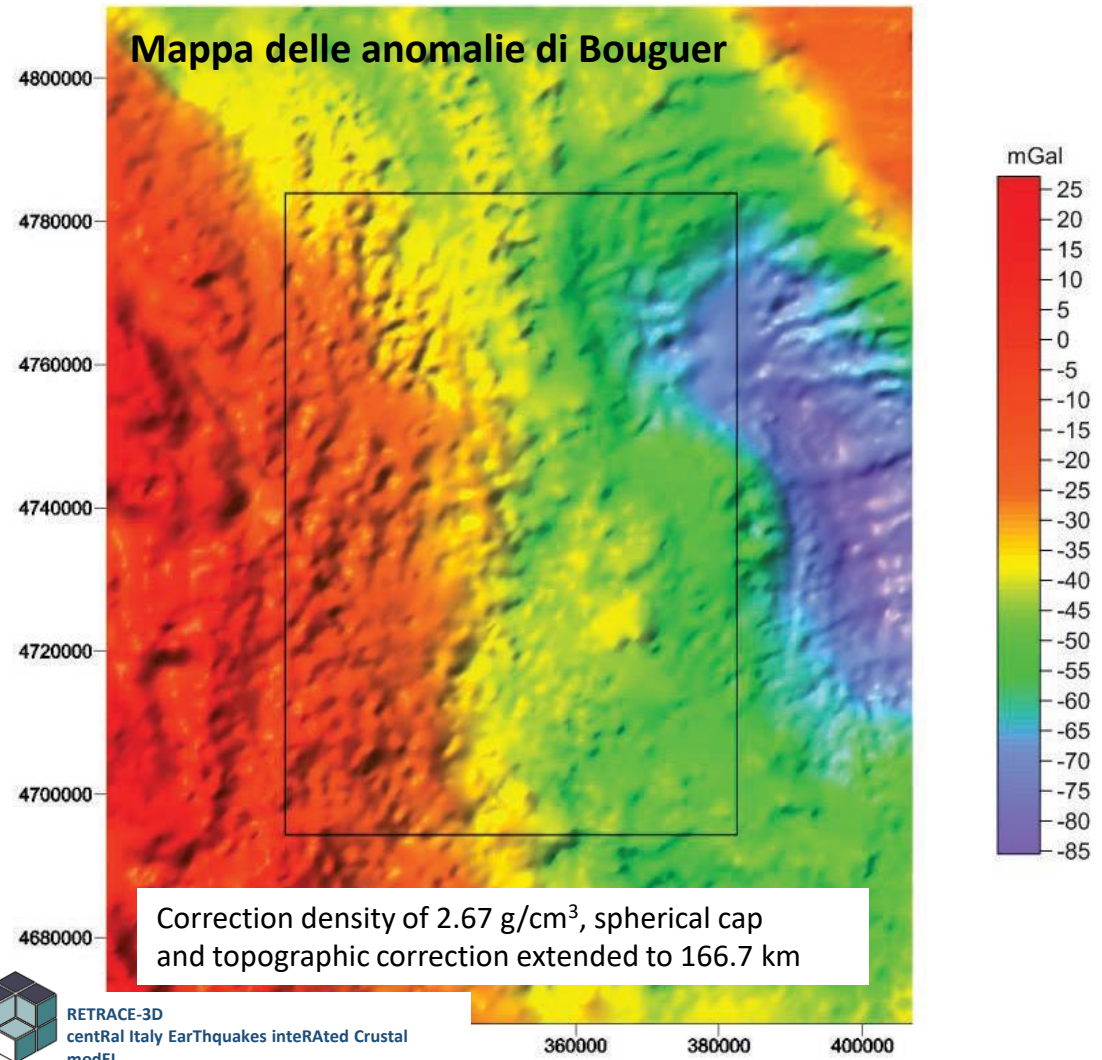


Vel-IO 3D scripts can be downloaded from:
<https://github.com/framae80/Vel-IO3D>

Integrazione, validazione, affinamento

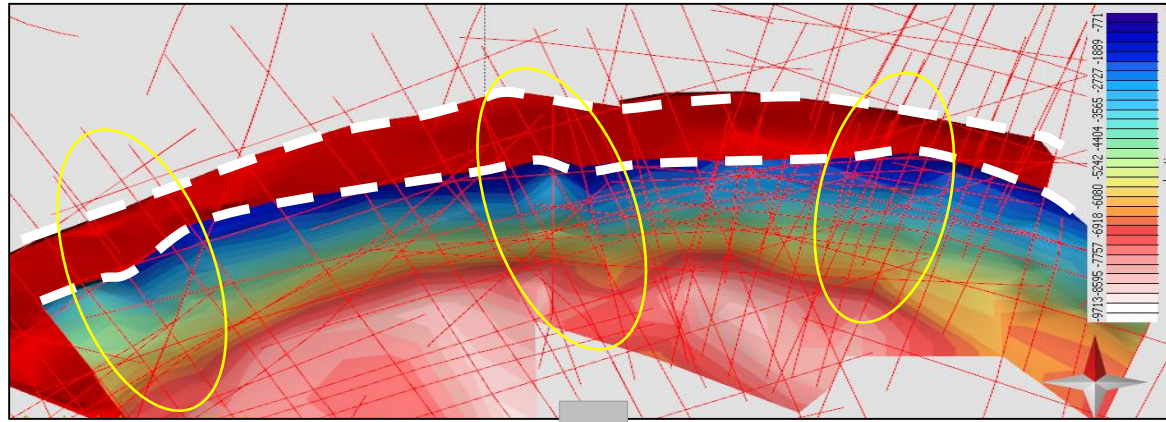
Buttinelli et al., ESC 2018

 RETRACE-3D
centRal Italy EarThquakes interRAted Crustal
modEL

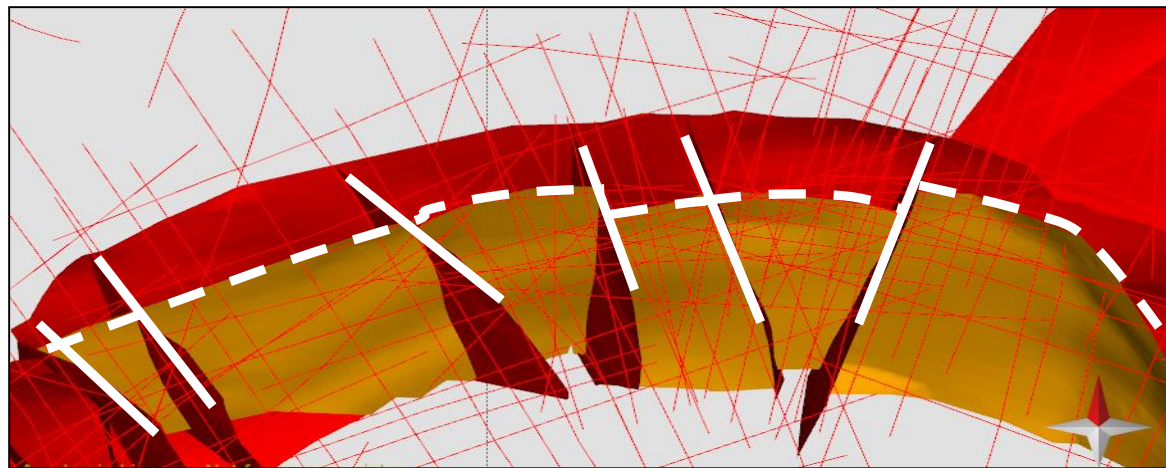


Rapporti ISPRA, 234/2015

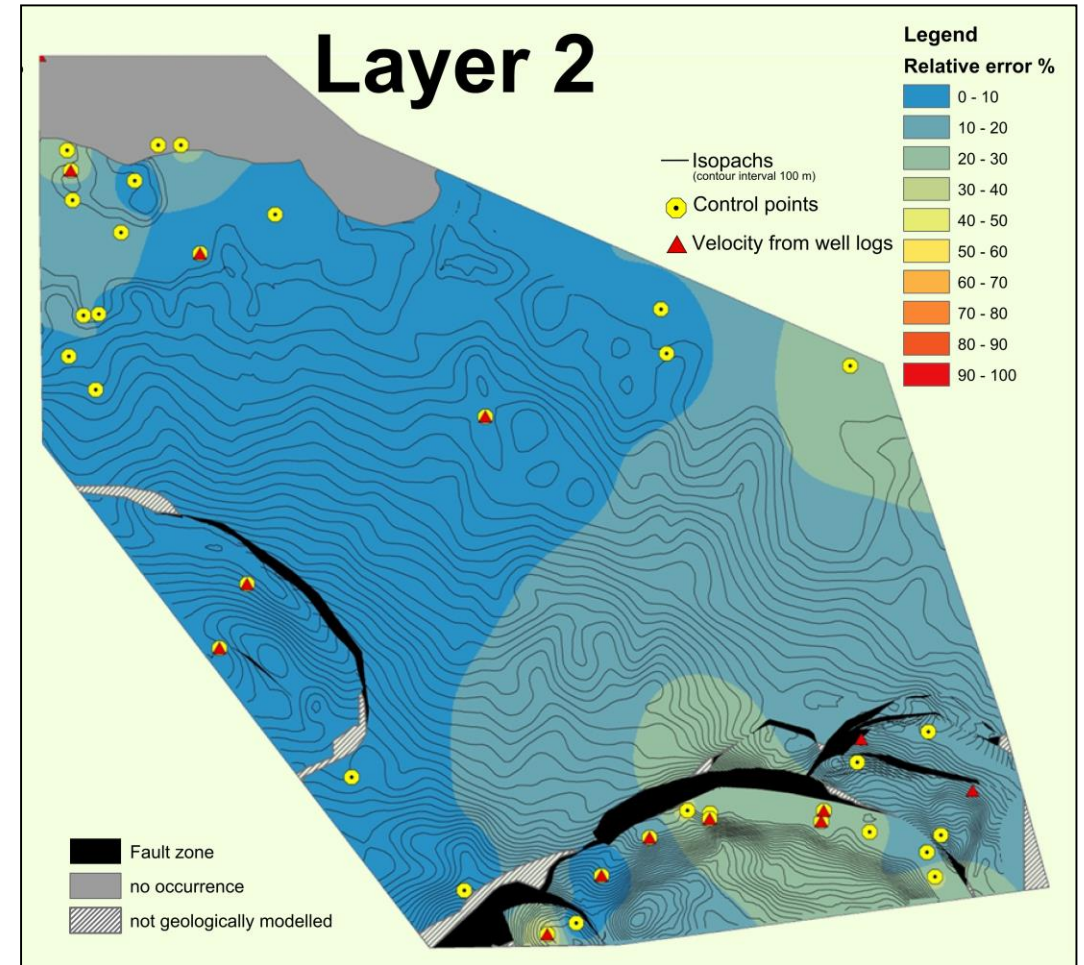
✓ Analisi di “anomalie” geometriche nelle superfici



✓ Inserimento di faglie presunte

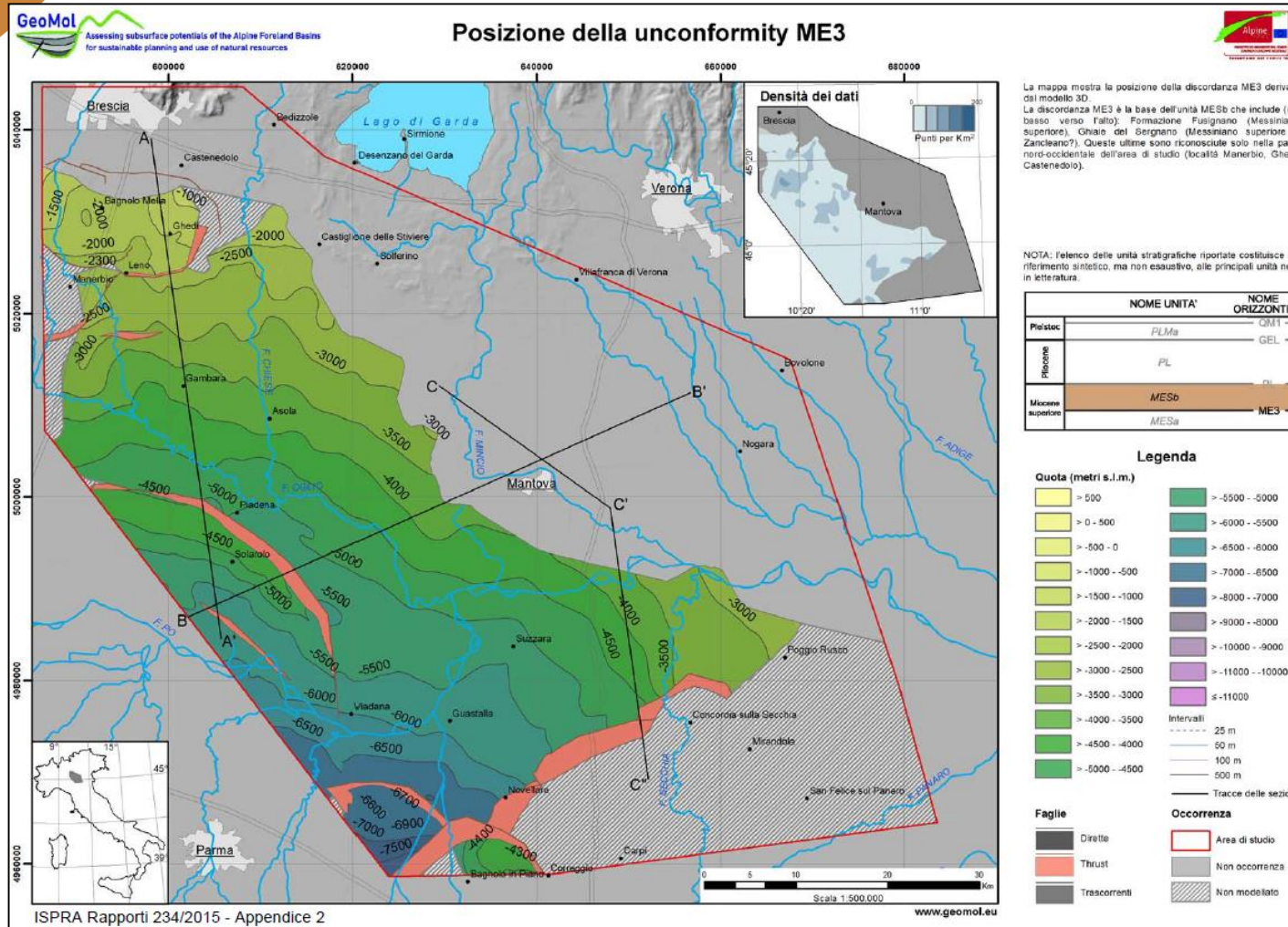


✓ Verifiche di congruenza e *reshape*

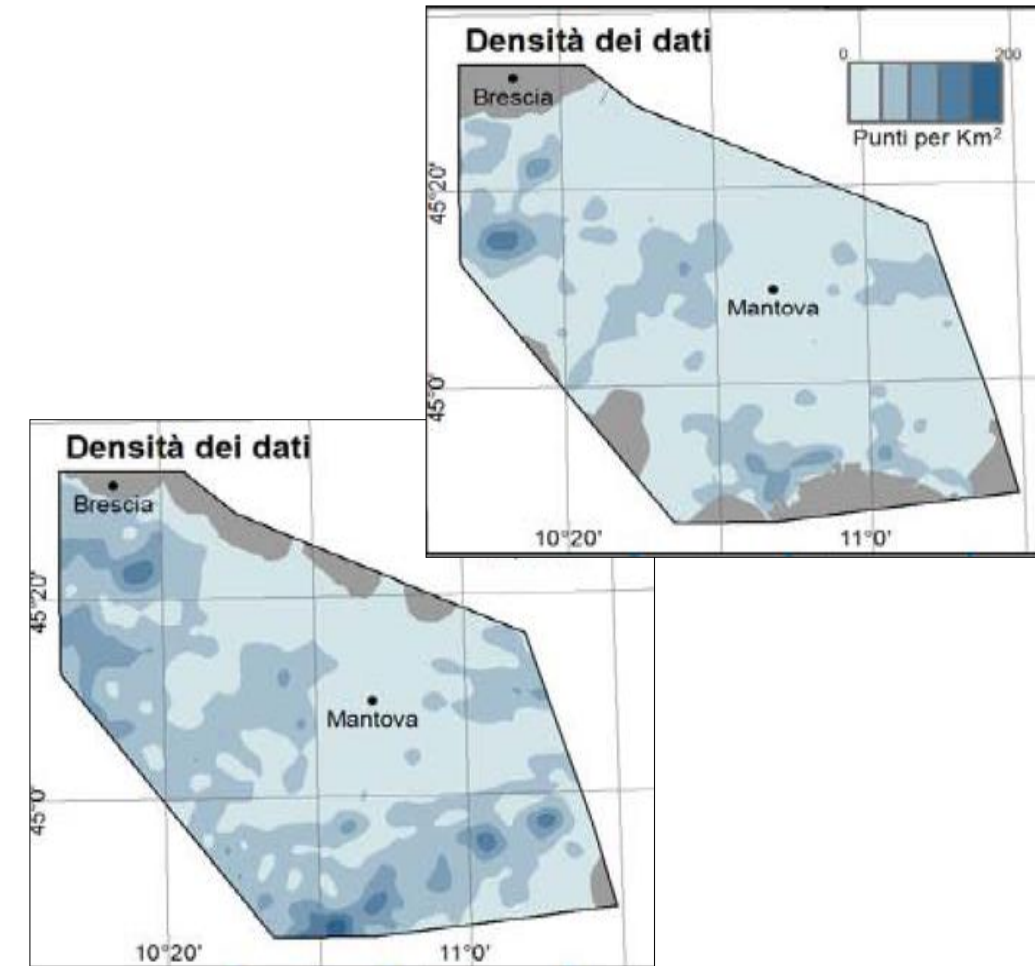


Confronto tra superfici in profondità e marker in pozzi non usati per la costruzione del modello di velocità

Comunicare l'incertezza



✓ Posizione/densità dei dati per i diversi orizzonti



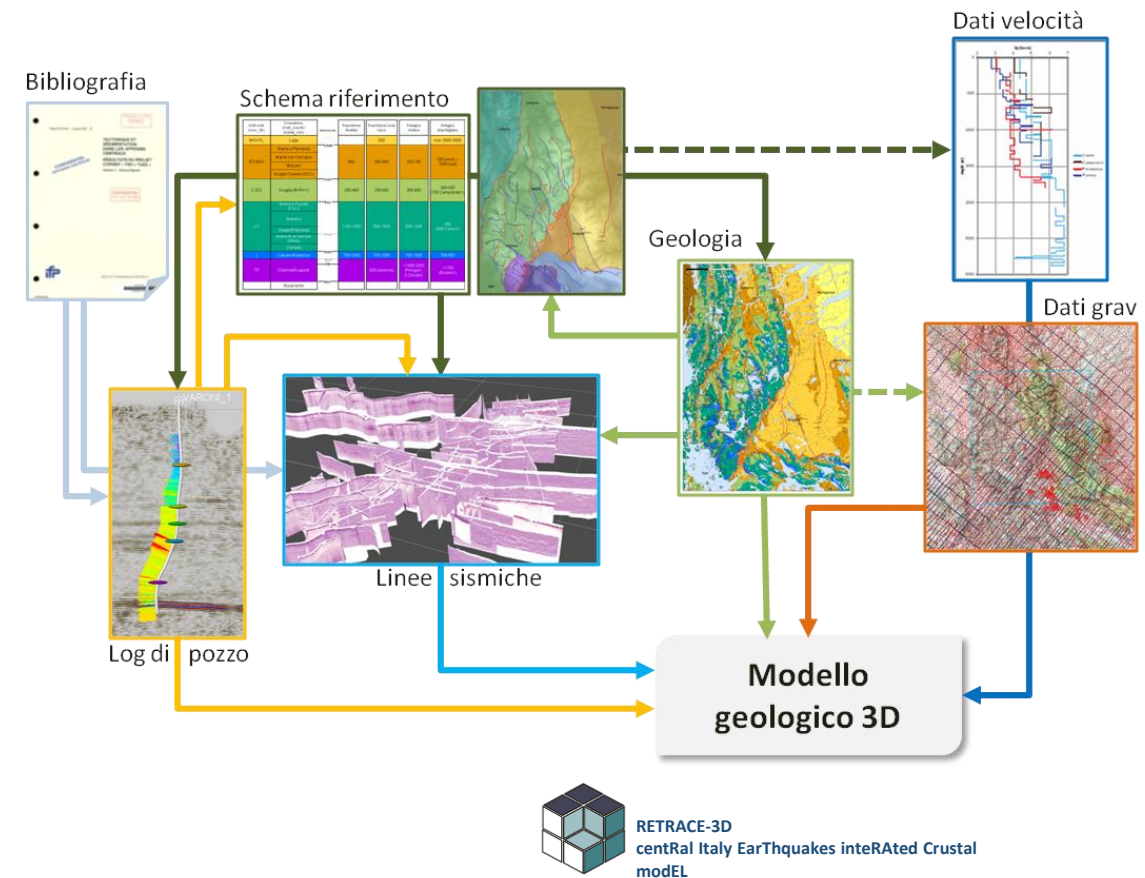
✓ Aree non modellate – per dati insufficienti

✓ Aree di non occorrenza

Integrazione di dati complessi è un lavoro *time-consuming*

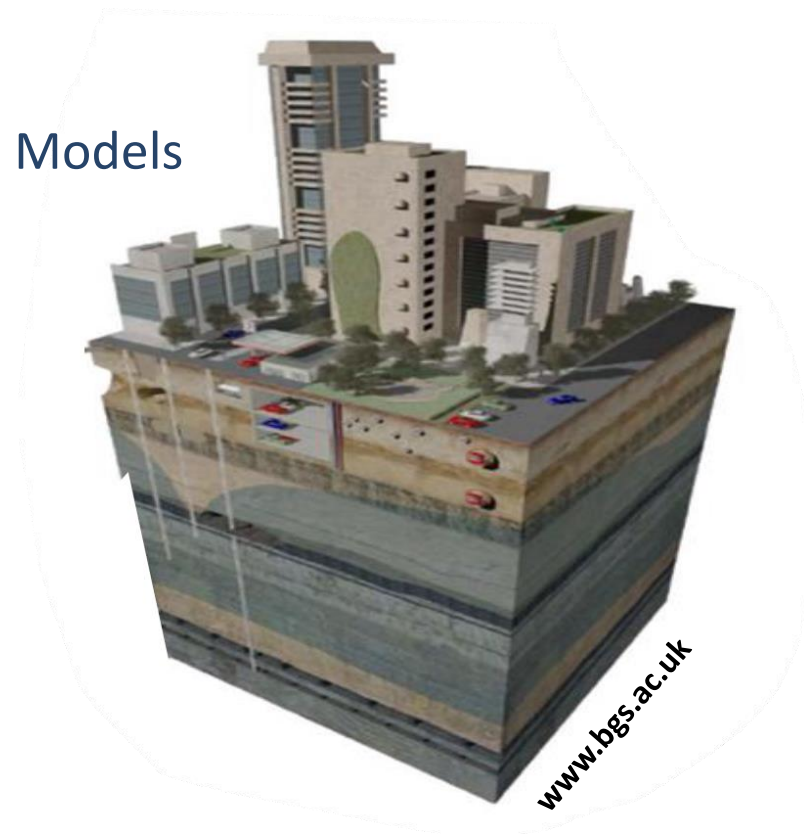
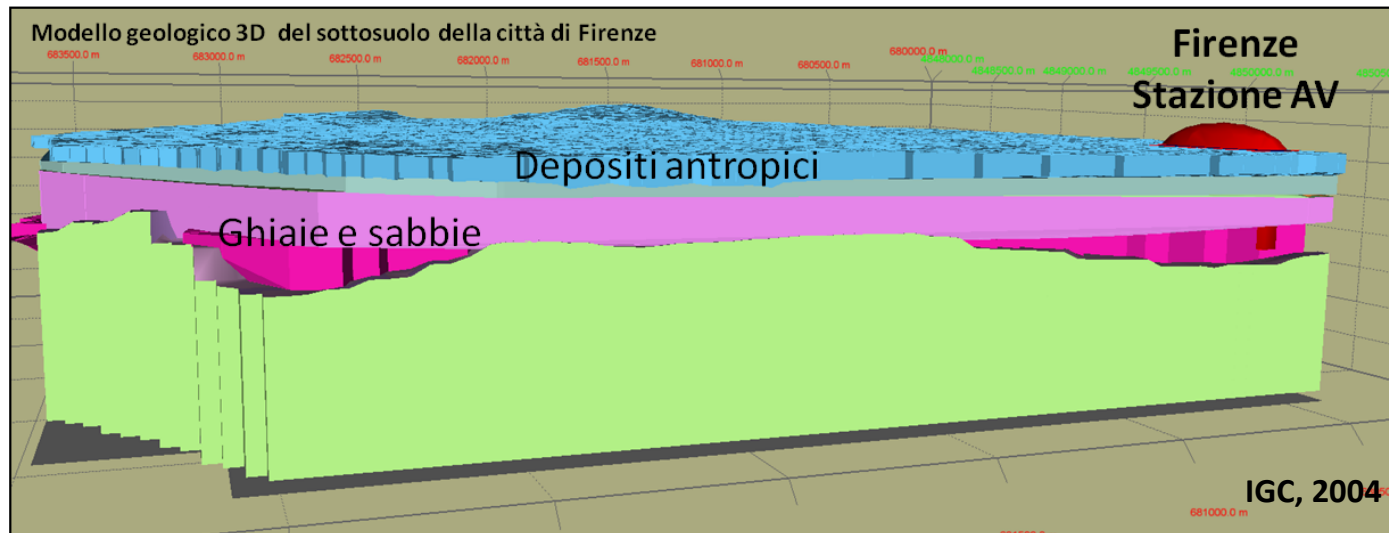
	GeoMol	HotLime	RETRACE-3D
area (km ²)	5,700	43,000	4,500
prof (km)	13	13	> 20
linee sism. (n)	759	795	180
linee sism. (km)	12,000	19,000	2,800
pozzi (n)	126	401*	21
dati vel. (tipo)	Well log vel Stacking vel	Well log vel	Well log vel
mod vel (n strati)	4	4	3
n. orizz. modell.	15	6	6
dati grav.	SI	---	SI
gg. dataroom	80 (3 postaz)	15 (3 postaz)	Dati originali

* 268 pubblici - Videpi

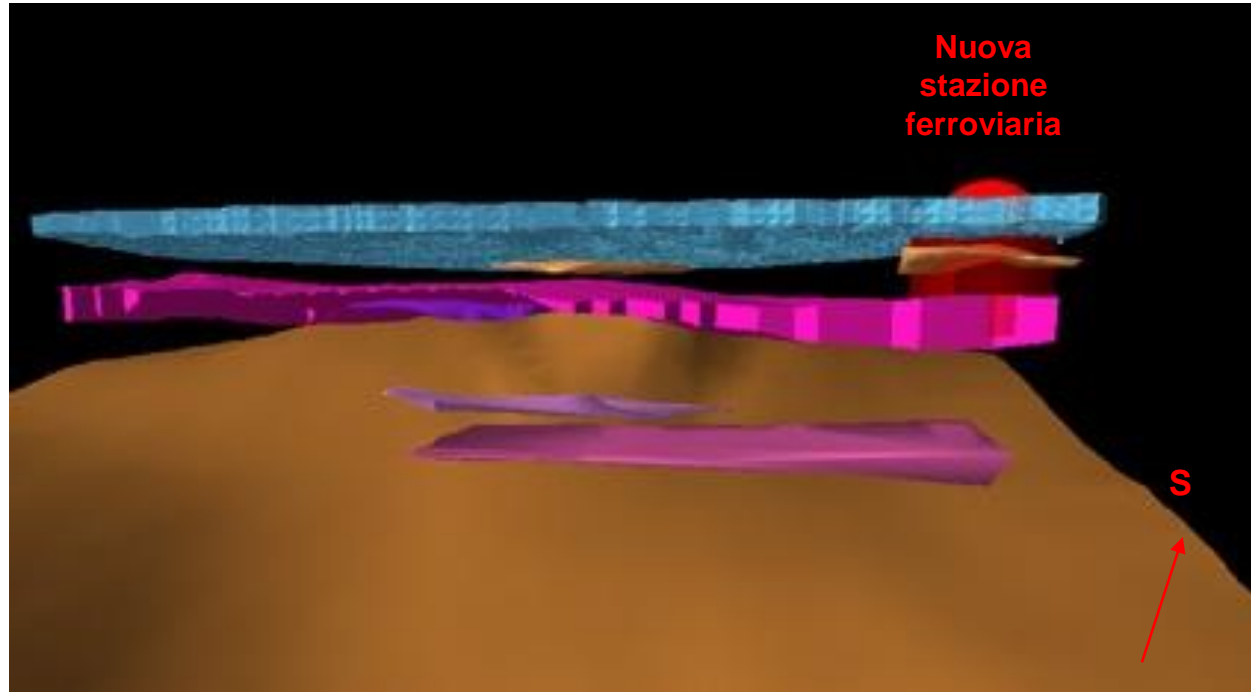


Modello geologico 3D di un'area urbana

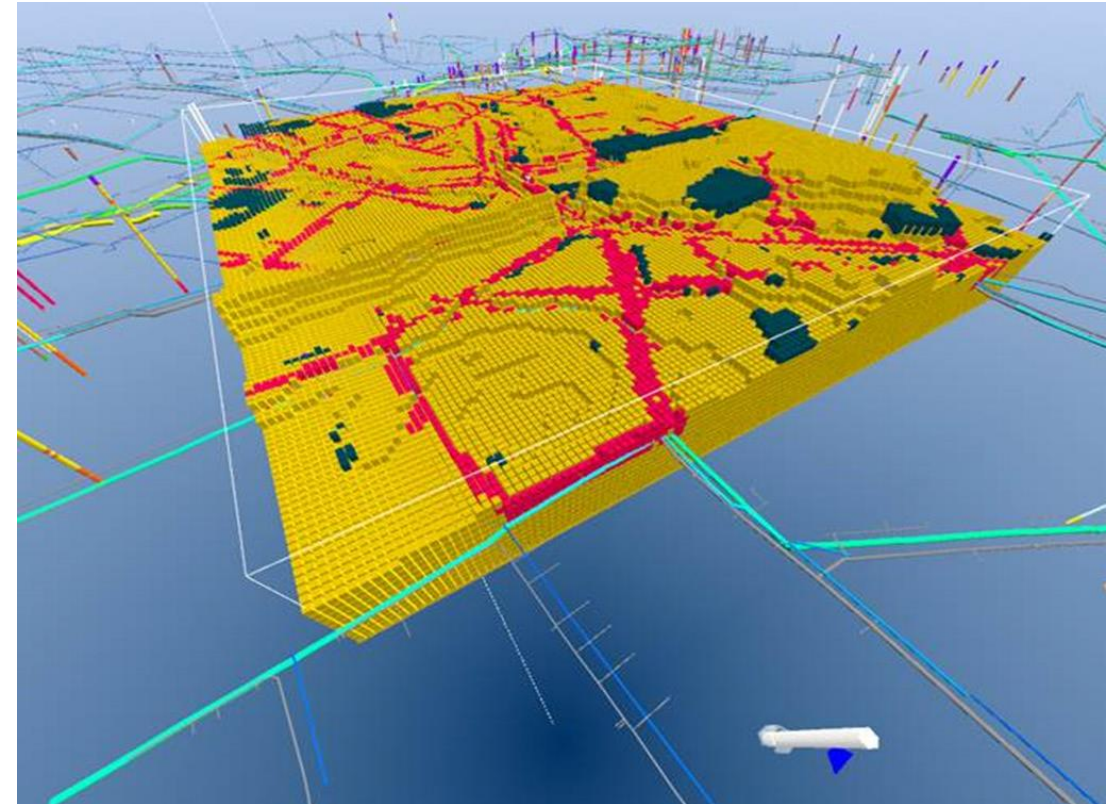
- ha scala di dettaglio diversa da modelli geologici “tradizionali”
- risponde a esigenze specifiche (infrastrutture, idrogeologia, risposta sismica locale, geotermia, sinkhole)
- deve tenere conto dei depositi antropici
- deve rispondere a esigenze di pianificatori e tecnici non-geologi
- deve avere una elevata capacità predittiva
- deve essere interoperabile con altri dati e BIM – Building Information Models
- può diventare un Digital Twin



Interazione con le strutture



Necessità di modellare i volumi (dimensione dei voxel)

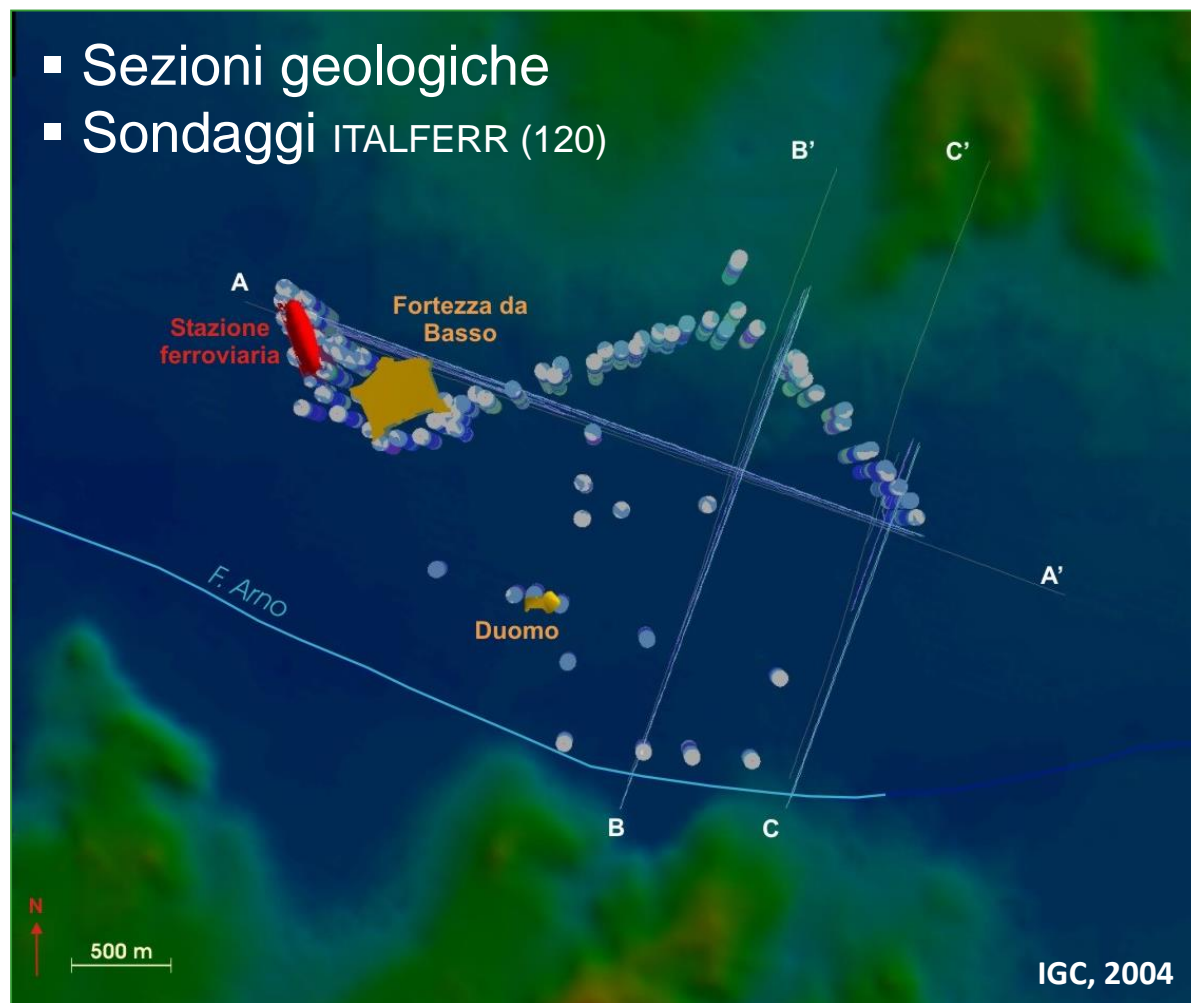


Pallesen & Jensen, 2015



TU1206 COST Sub-Urban WG2 Report, 2017

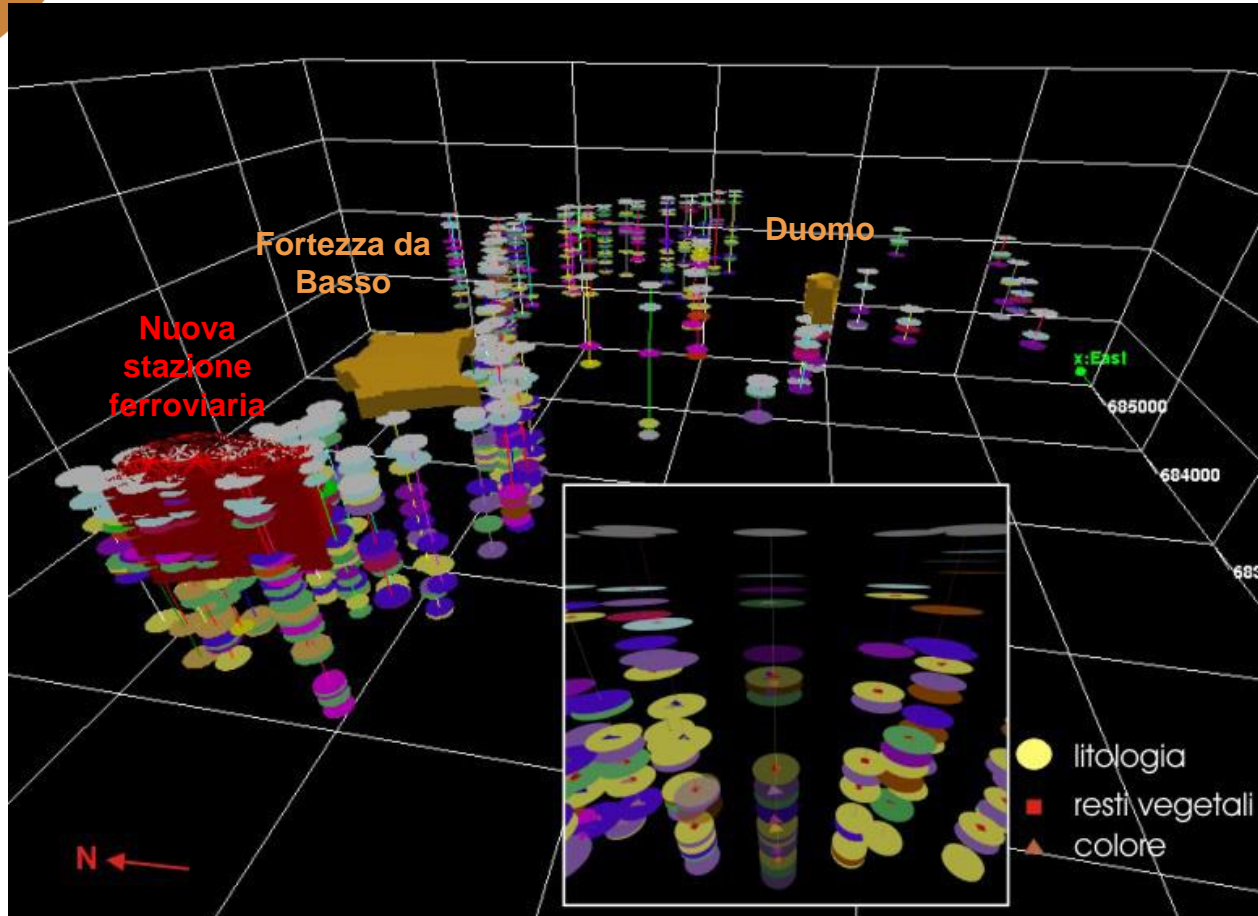
- Sezioni geologiche
- Sondaggi ITALFERR (120)



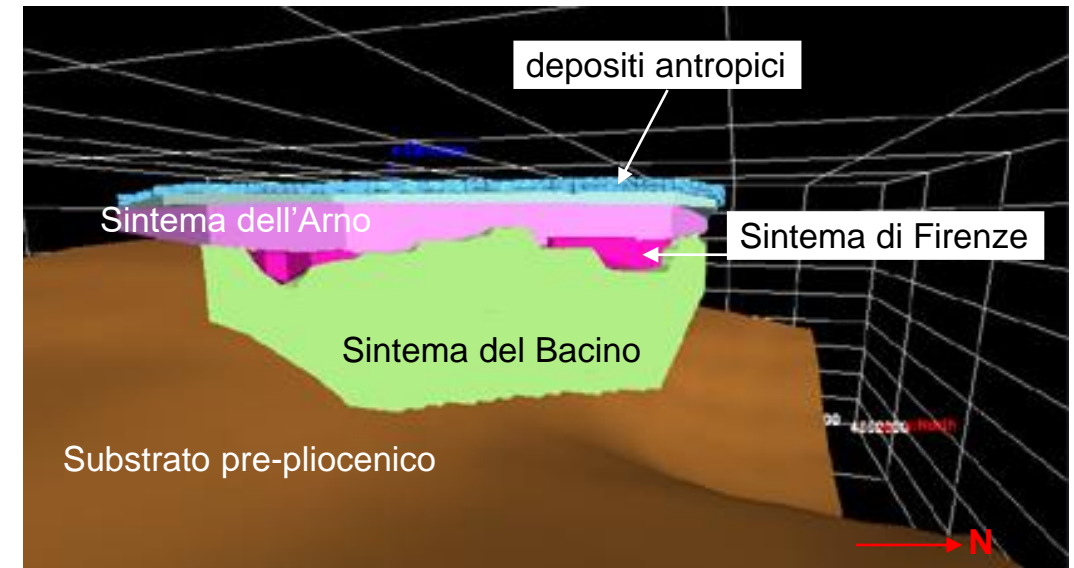
Distribuzione dei dati ha alto impatto sulla qualità e la capacità predittiva del modello

Depositi antropici hanno altissima variabilità spaziale, diversa dai corpi geologici controllati da meccanismi deposizionali

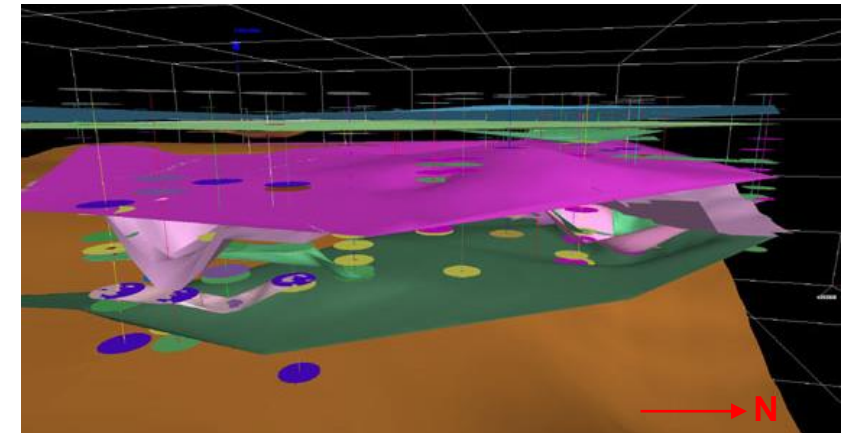
Definire attributi rilevanti ai fini dell'applicazione attesa



Codifica litologica e attributi utili alla differenziazione dei depositi per la specifica applicazione



Necessità di disporre di un modello stratigrafico di riferimento



Modelli geologici 3D per la geotermia

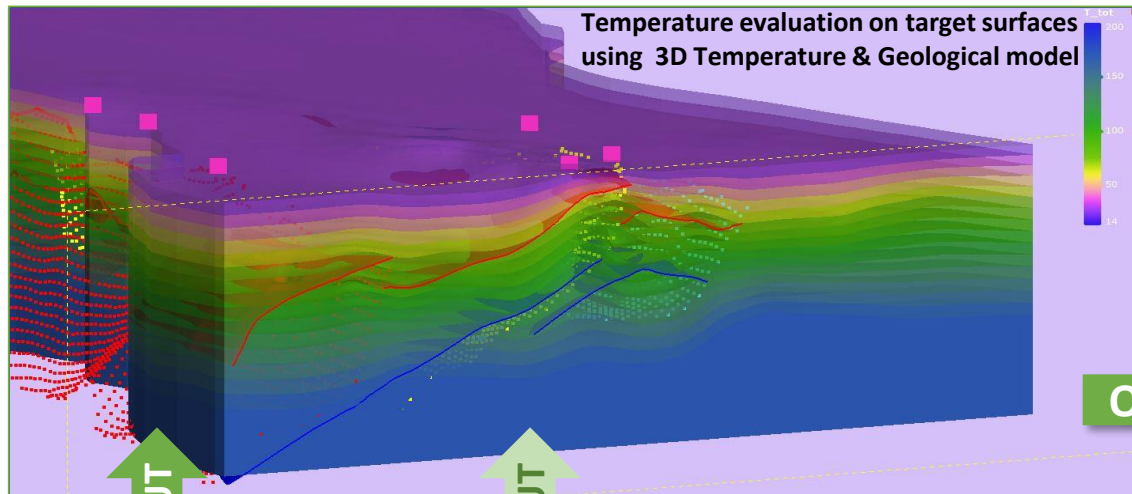
3D GEOLOGICAL MODEL OF THE PO PLAIN SUBSURFACE is a basic input for

▪ 3D Temperature Model
Analytical a-priori model

Results of HotLime
GeoERA

OUTPUT

Thematic Maps
Data analysis in ArcGIS



INPUT

Geological Model
[x,y,z points]

INPUT

T (°C) [x,y,z points]

Data analysis in GIS

Temperature evaluation

Geothermal Gradient (K0 - Siliciclastic succession)

Geothermal Gradient (K1 - Carbonate succession)

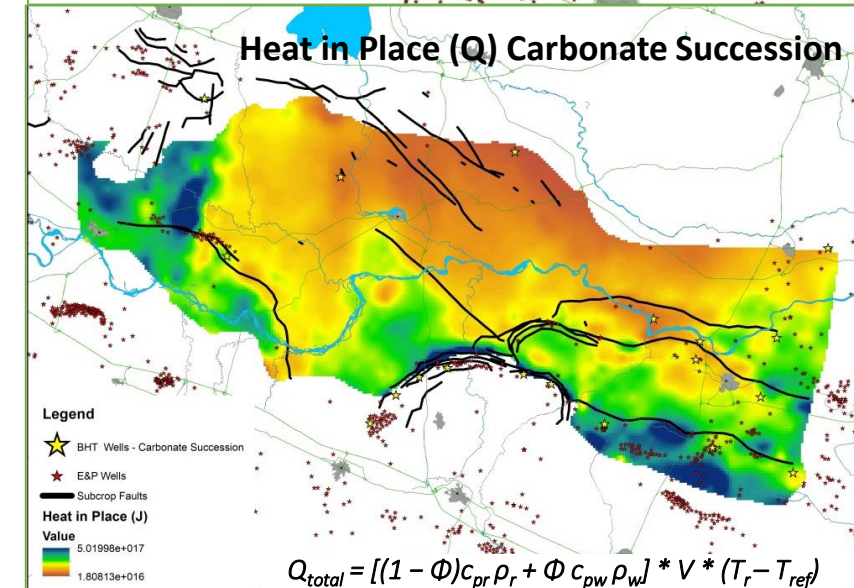
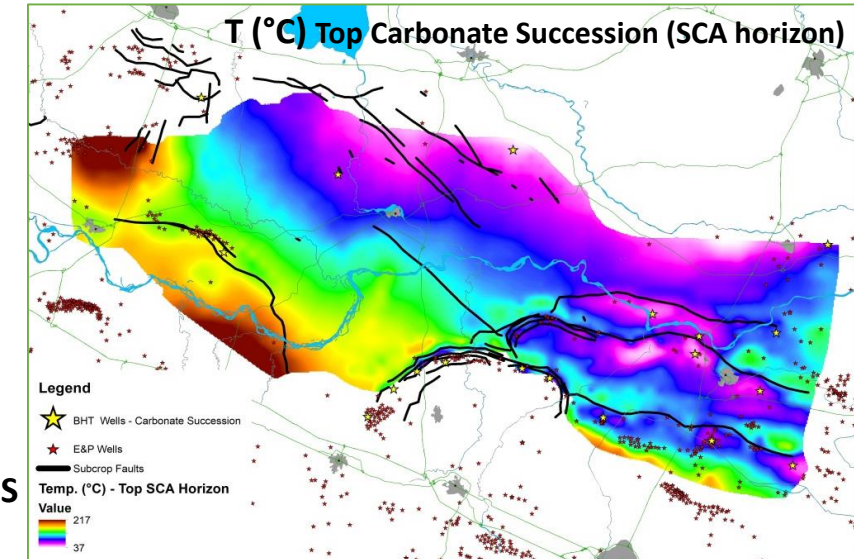
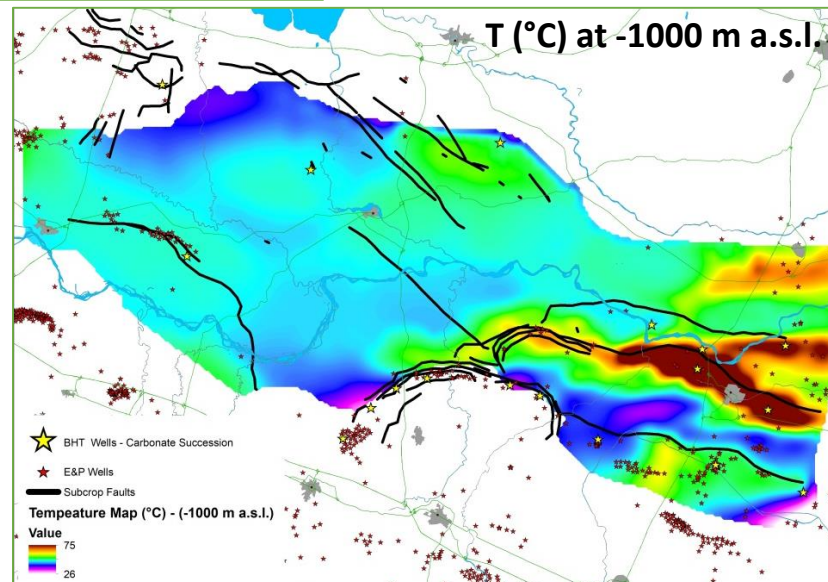
BHT temperature analysis
& analytical/empirical correction

The dataset

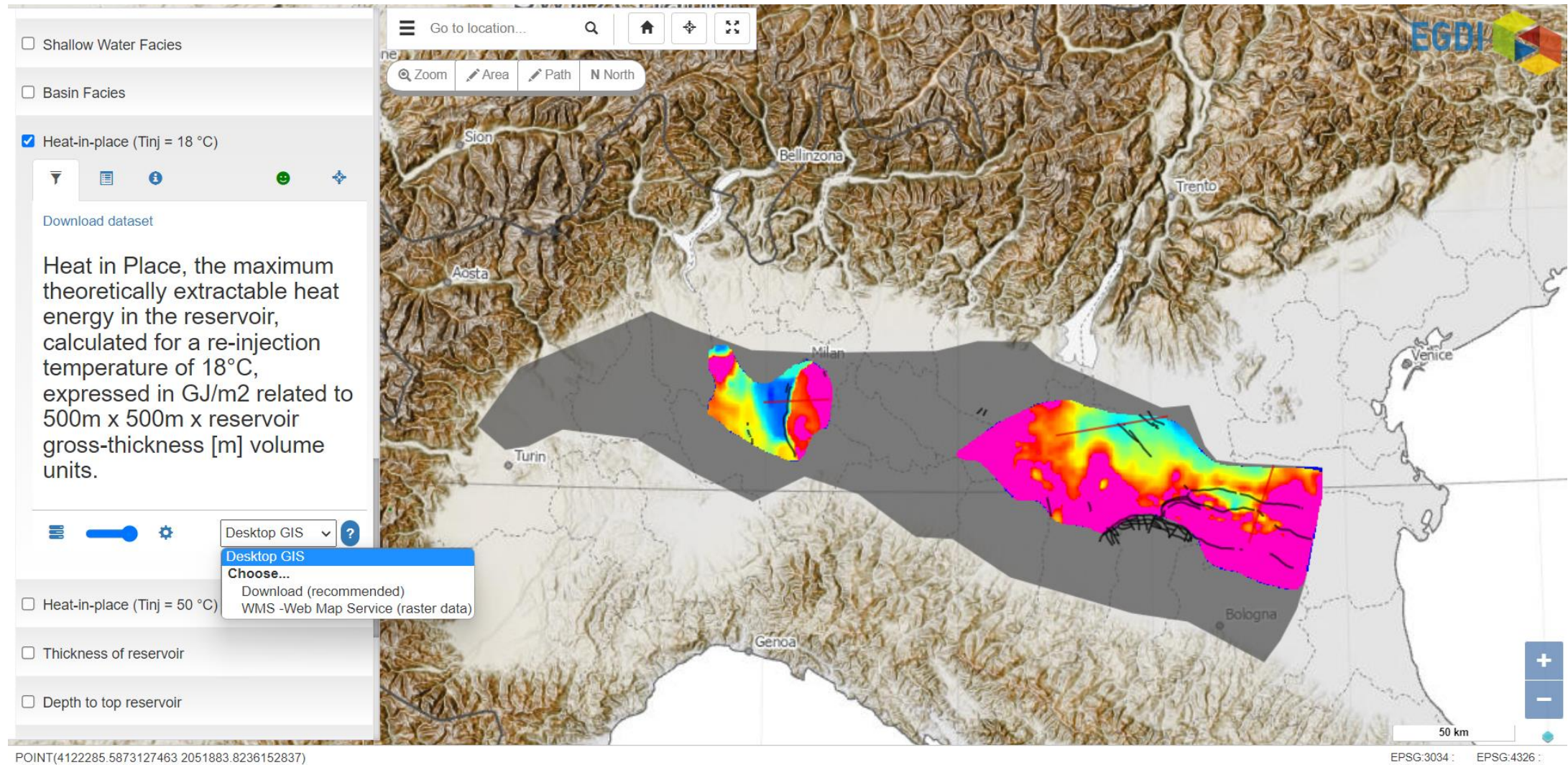
Bottom Hole Temperature from E&P well profiles

40 data - siliciclastic succession

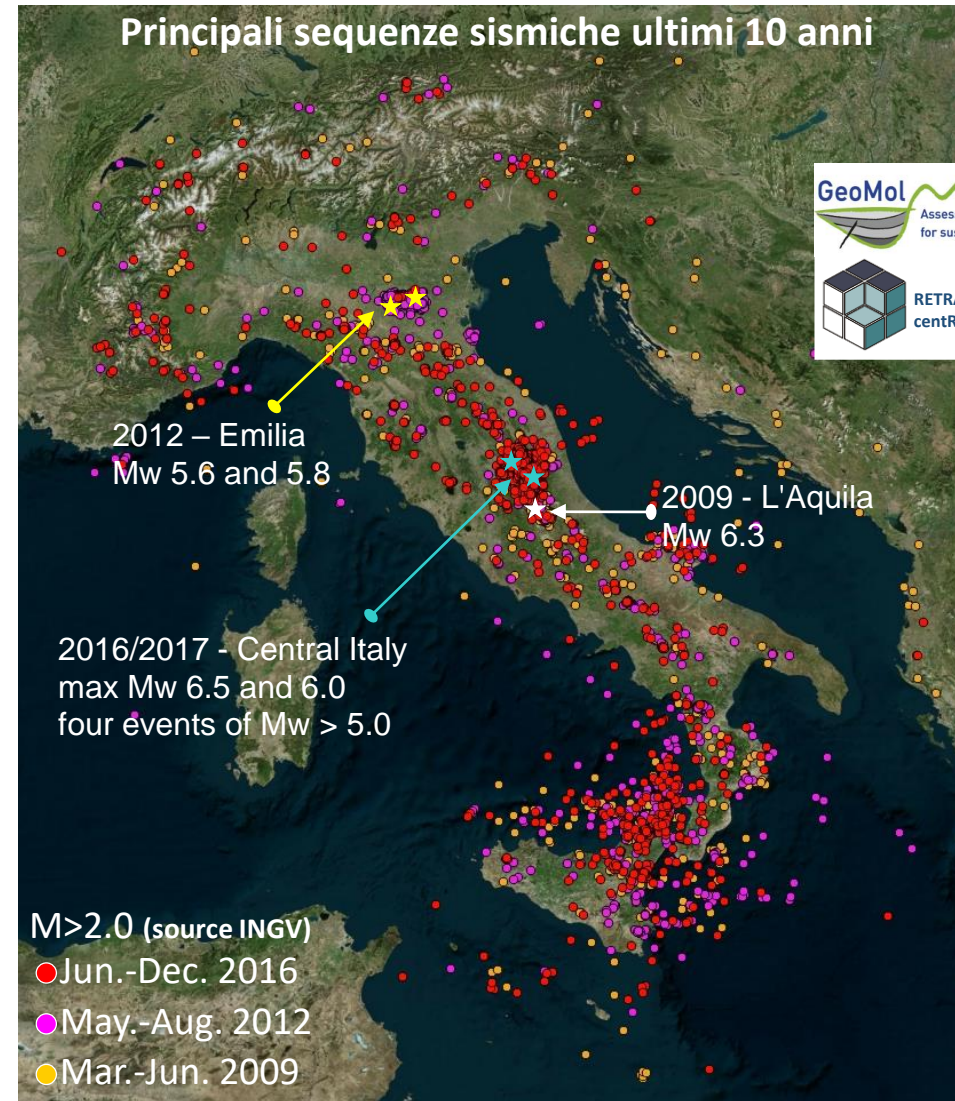
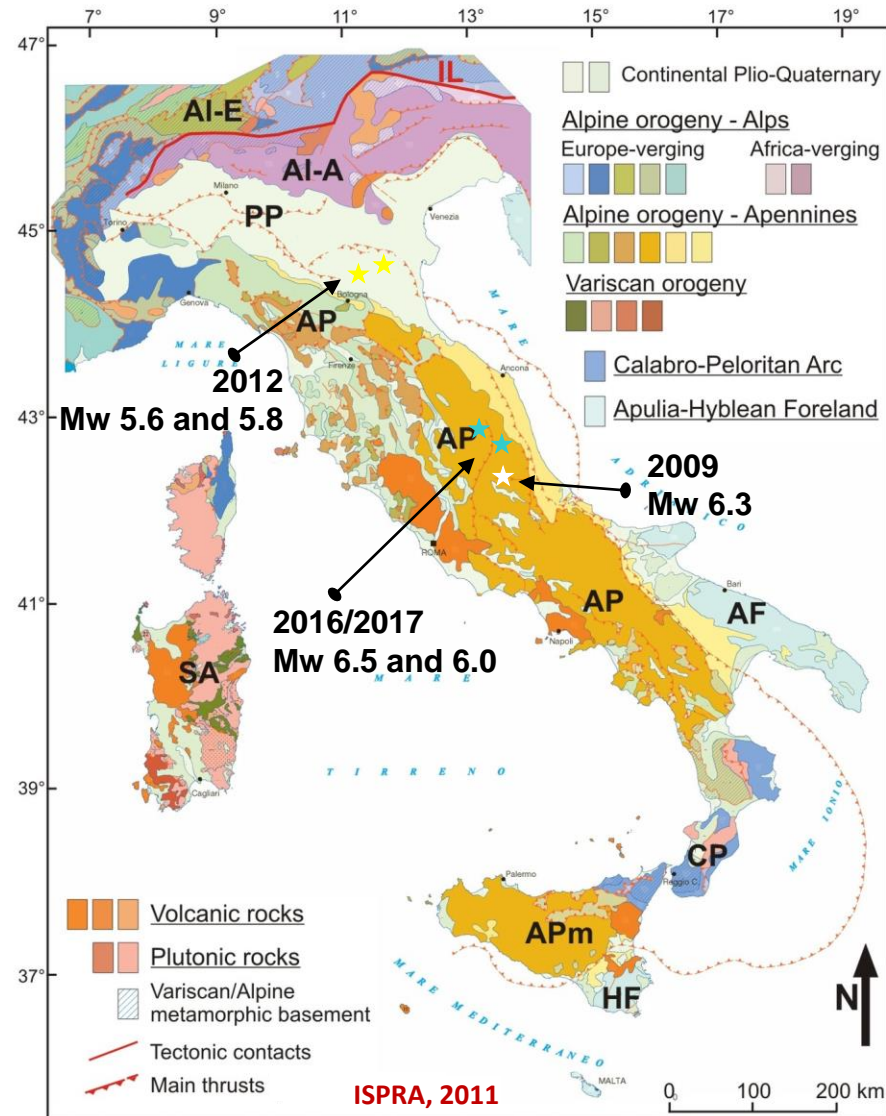
19 data - carbonate succession



$$Q_{total} = [(1 - \Phi)c_{pr}\rho_r + \Phi c_{pw}\rho_w] * V * (T_r - T_{ref})$$



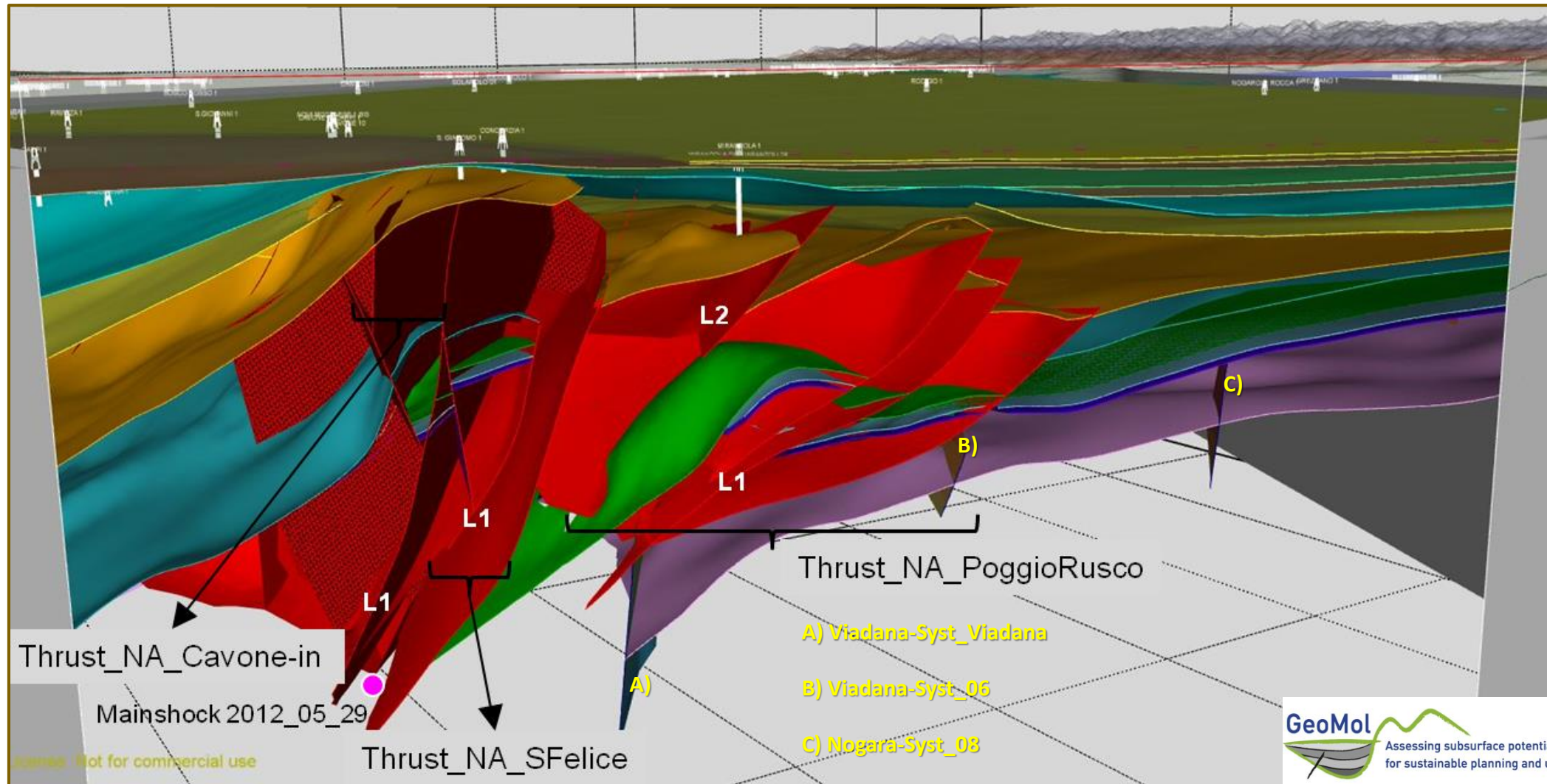
Modelli geologici 3D per la tettonica attiva



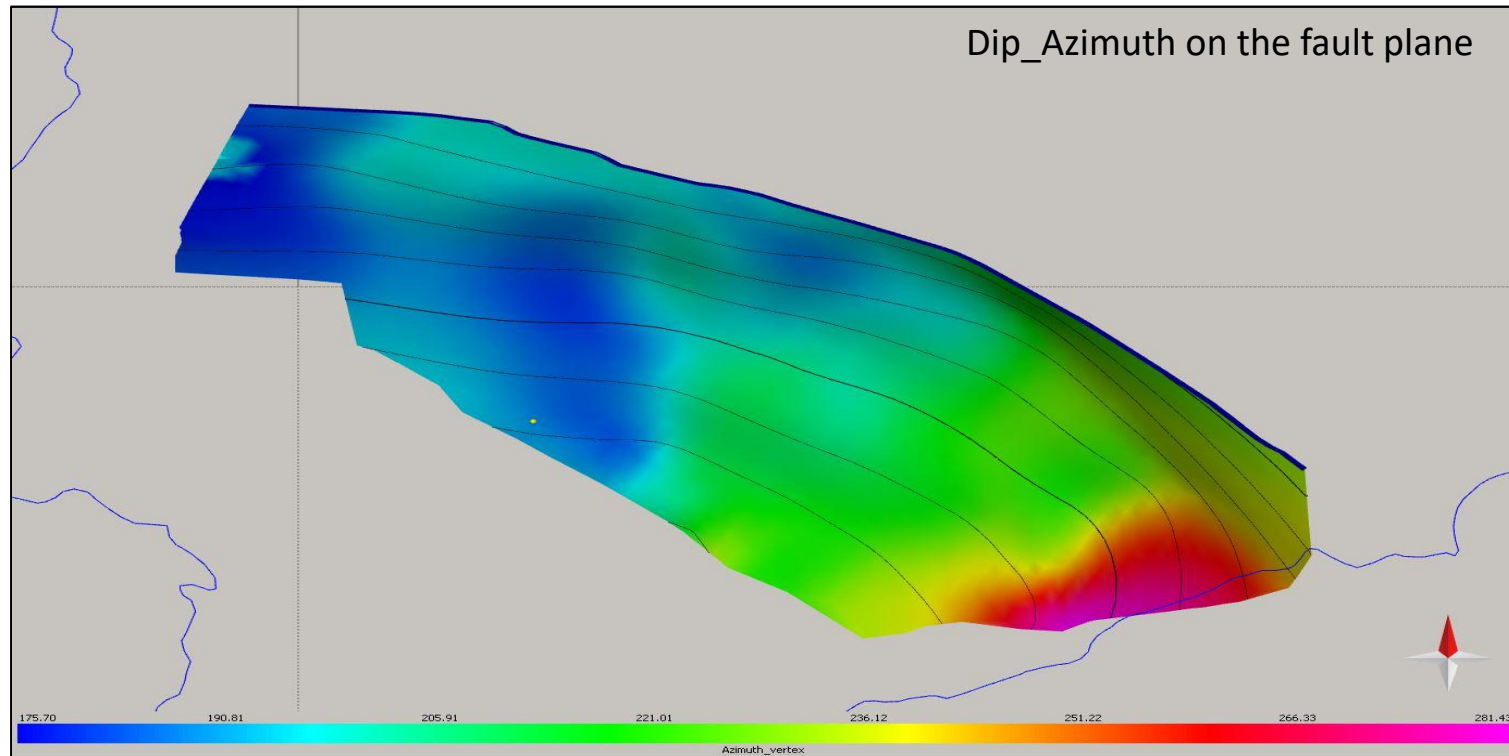
Progetti Sismologici



Massimizzare le informazioni geologiche



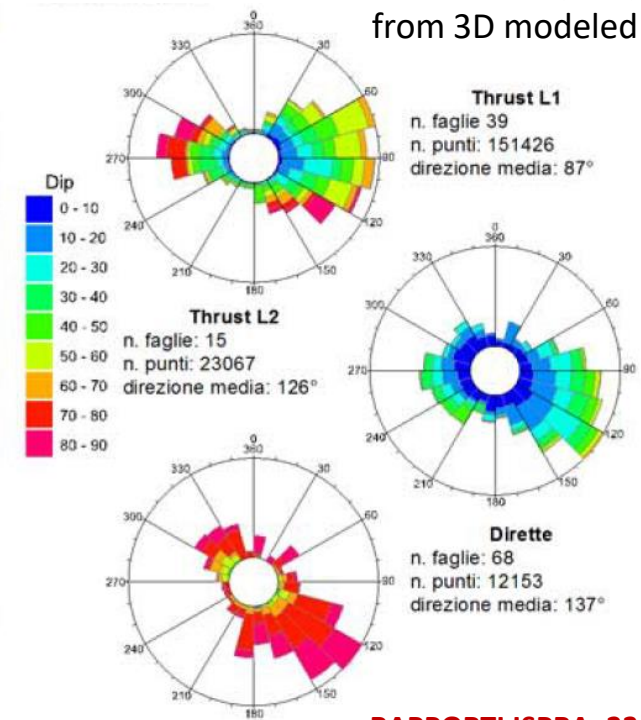
Massimizzare le informazioni geologiche



Modelli geologici 3D restituiscono:

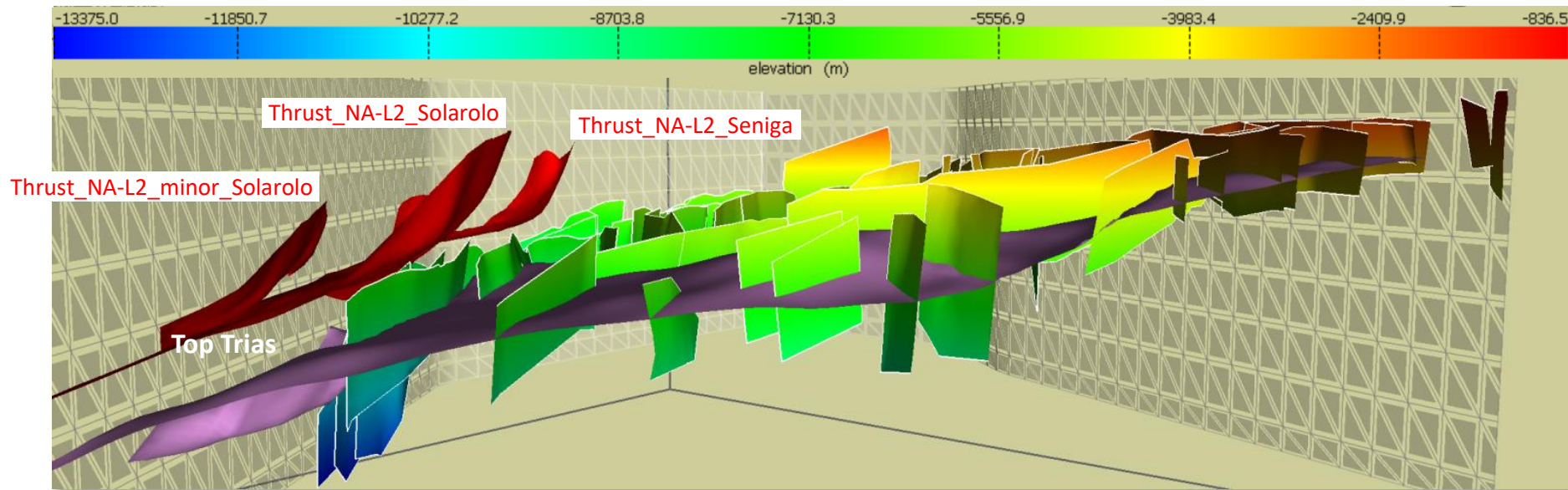
- Geometria 3D (posizione, azimuth, dip)
- posizione limite superiore (upper tip)
- livello di scollamento (per thrust)
- età orizzonte fagliato/deformato più giovane

Strike and dip of points from 3D modeled faults

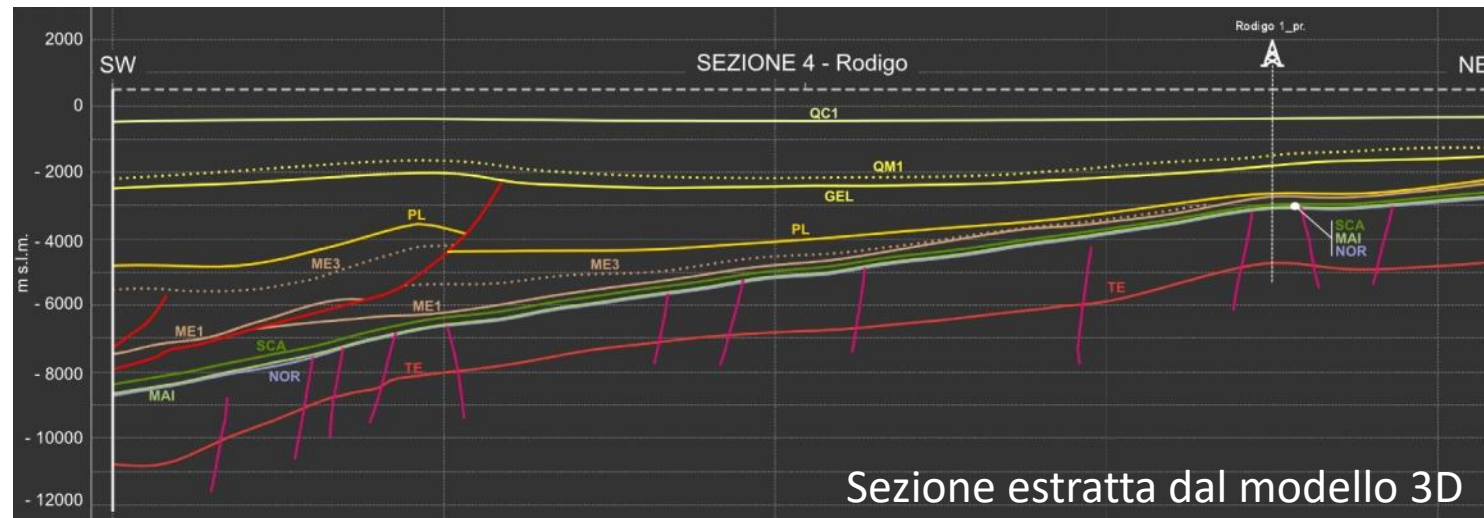


RAPPORTI ISPRA ,234 /2015

Massimizzare le informazioni geologiche

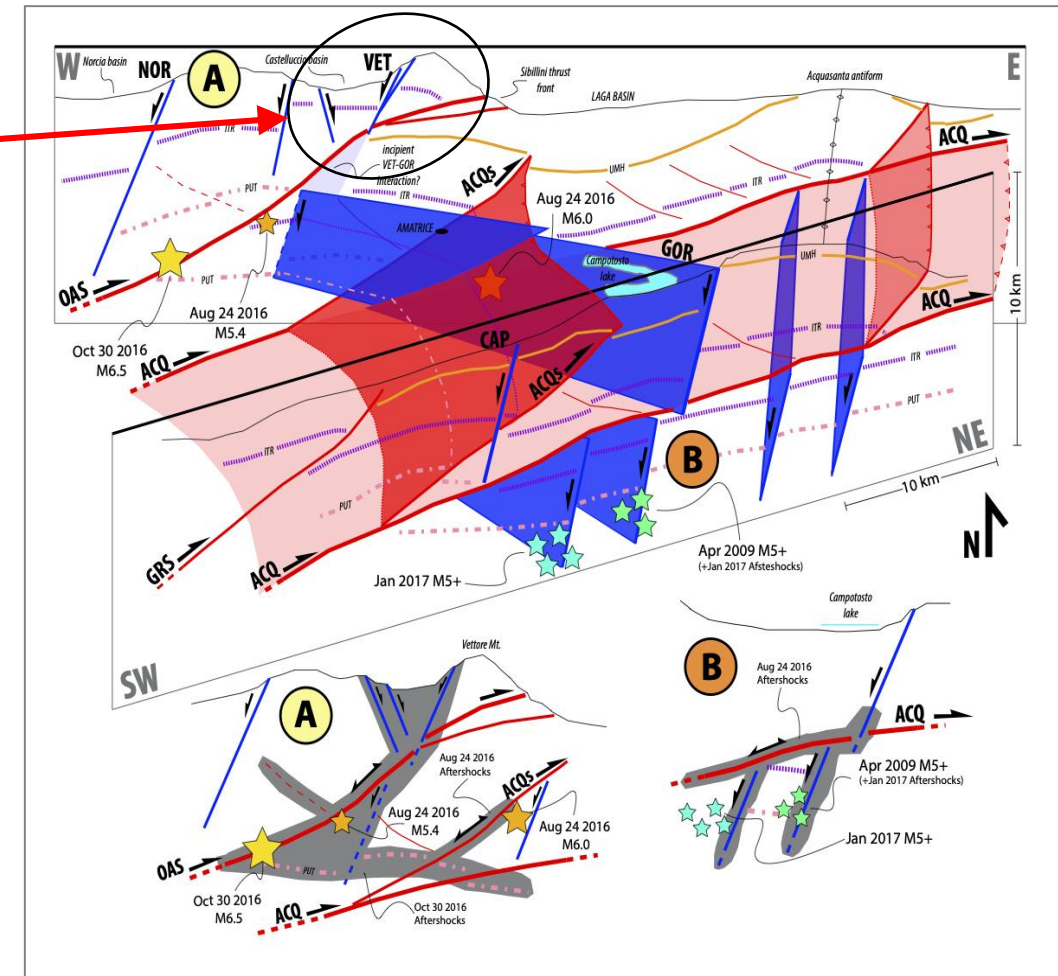
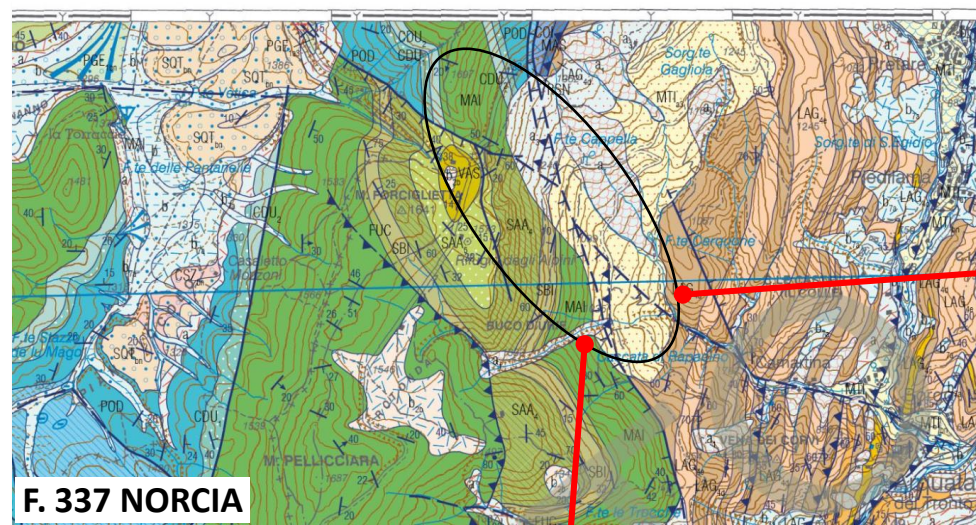


Relazioni tra sistemi di faglia



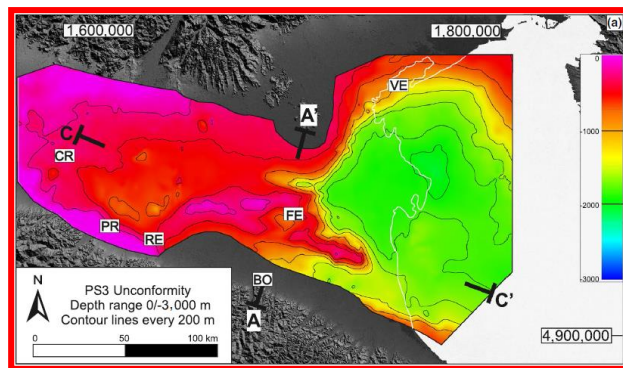
e.g. ruolo delle faglie ereditate e ipotesi di riattivazione

Sequenza sismica Italia centrale 2016-2017

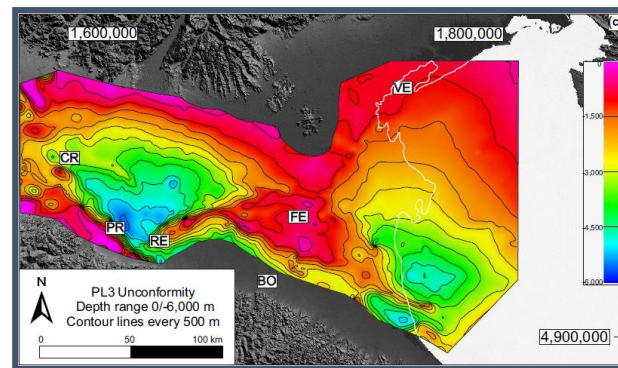


Buttinelli et al., Tectonophysics, 2021

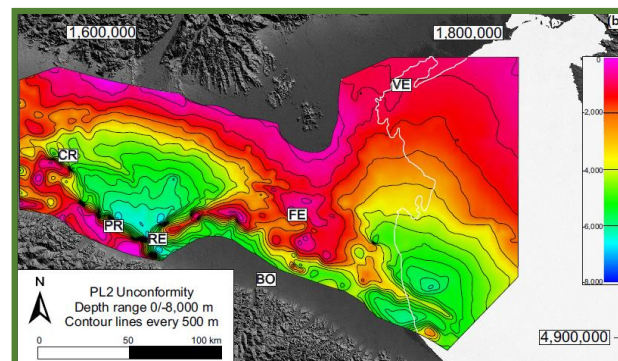
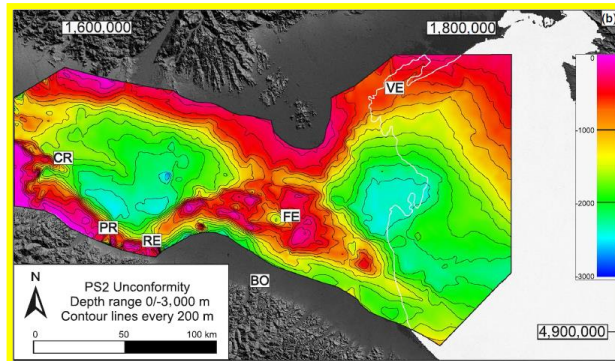
Massimizzare le informazioni geologiche



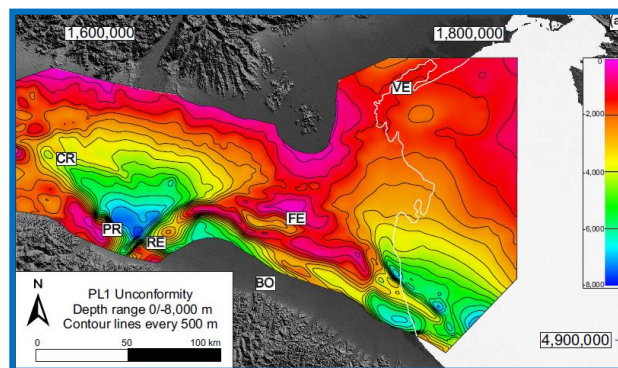
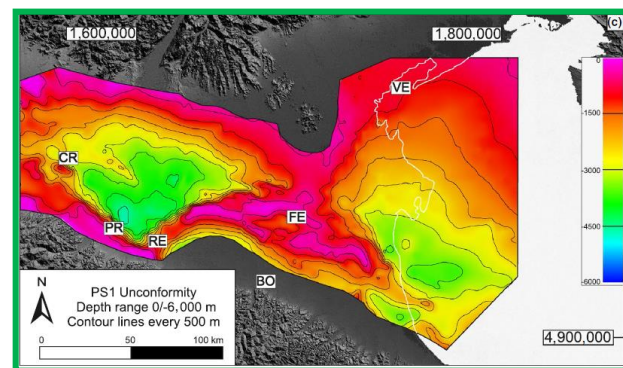
0.87 Ma



PLEISTOCENE



PLIOCENE

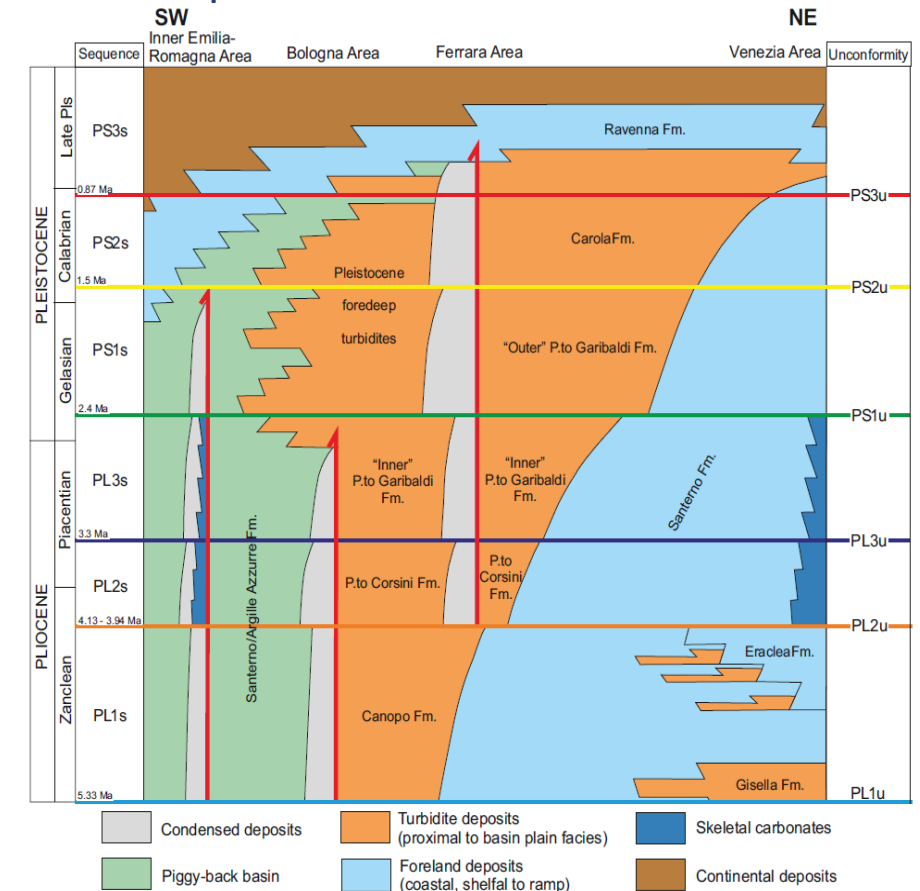


5.33 Ma

MODELLAZIONE GEOLOGICA 3D: APPLICAZIONI

Solidi vincoli stratigrafici
basati su dati di superficie e sottosuolo

✓ vincoli per la storia sismotettonica



Amadori et al, Bas Res (2019)

✓ identificazione strutture elusive e di strutture attive cieche

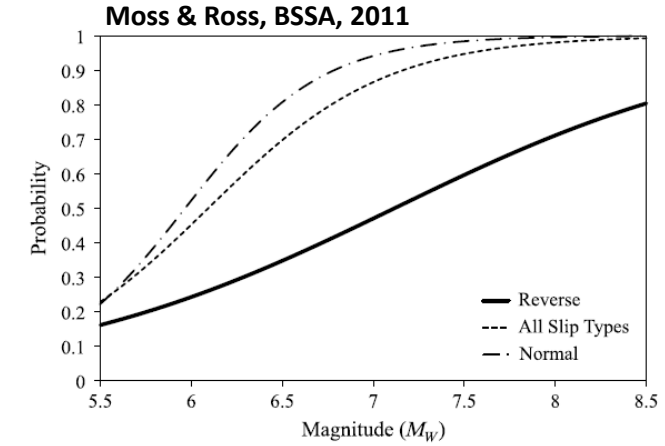
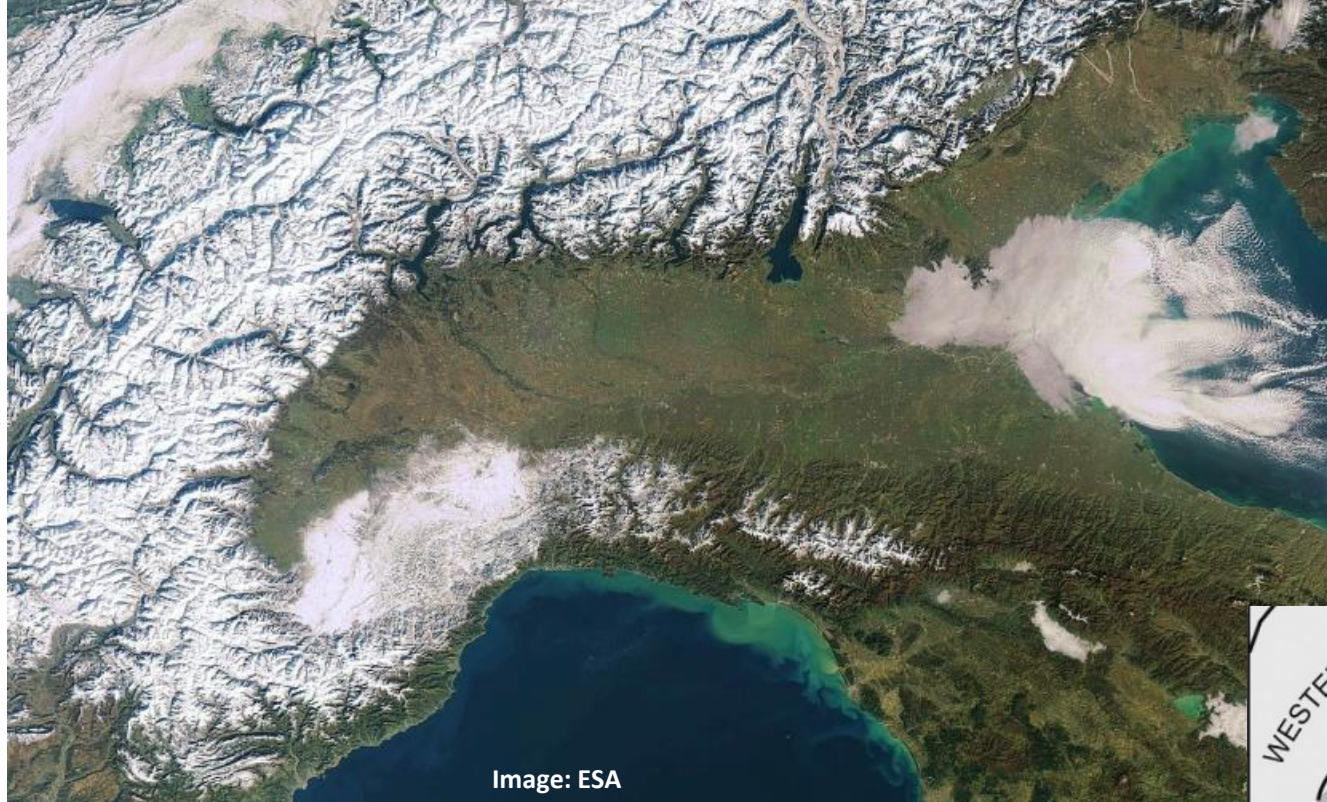
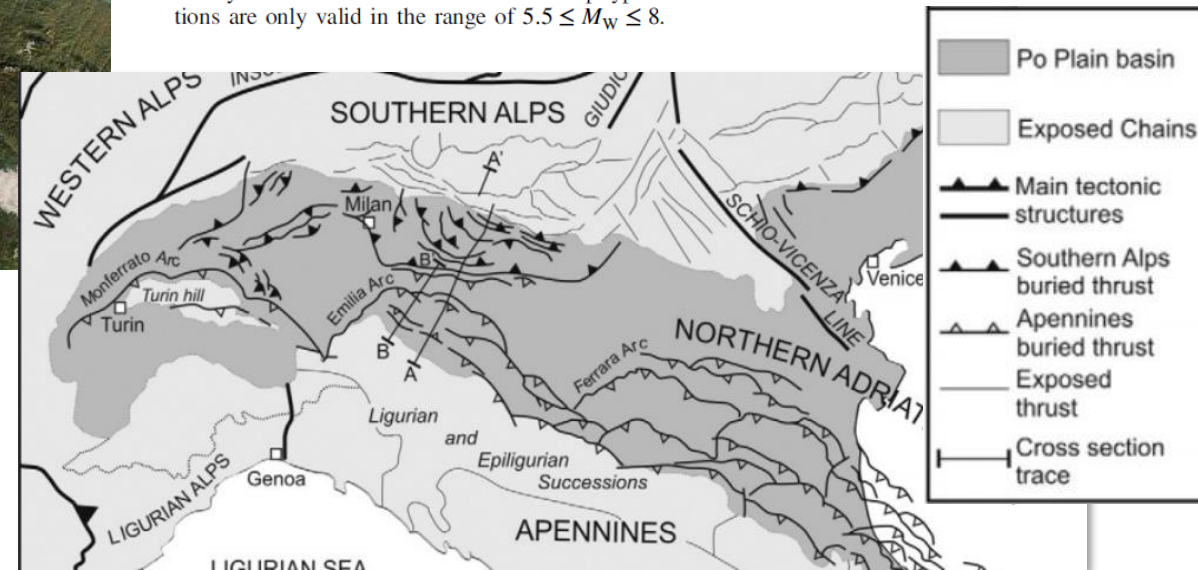
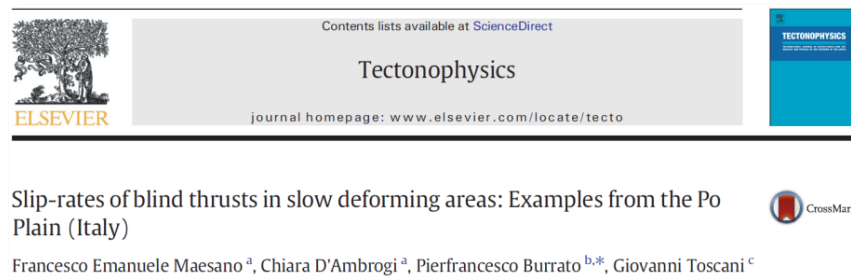
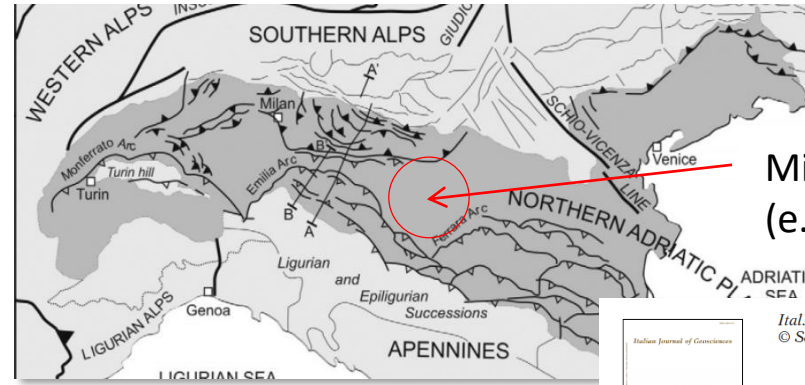
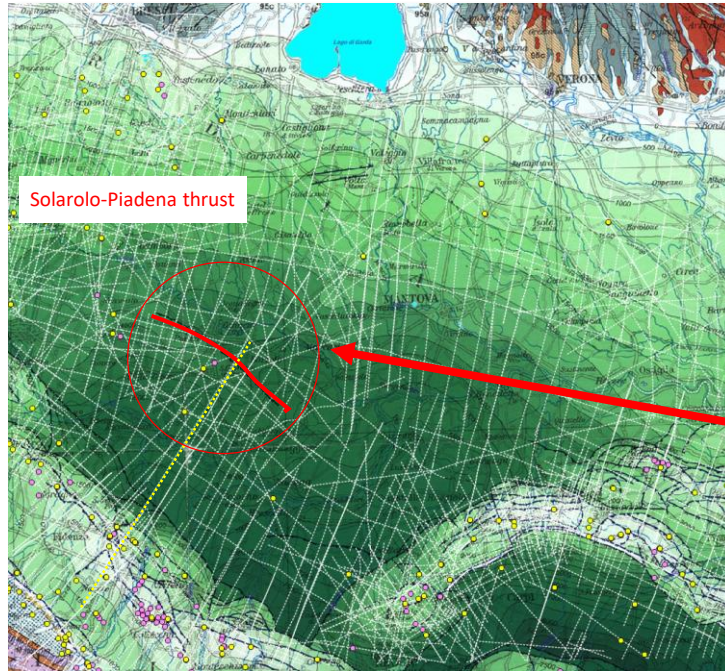


Figure 1. Probability of surface rupture for reverse, normal, and all slip types. The normal and all slip types are from [Youngs et al. \(2003\)](#). Empirical distributions are fit using logistic regression for a dichotomous outcome. The probability for reverse events is significantly lower than that of normal and all slip types. These distributions are only valid in the range of $5.5 \leq M_w \leq 8$.





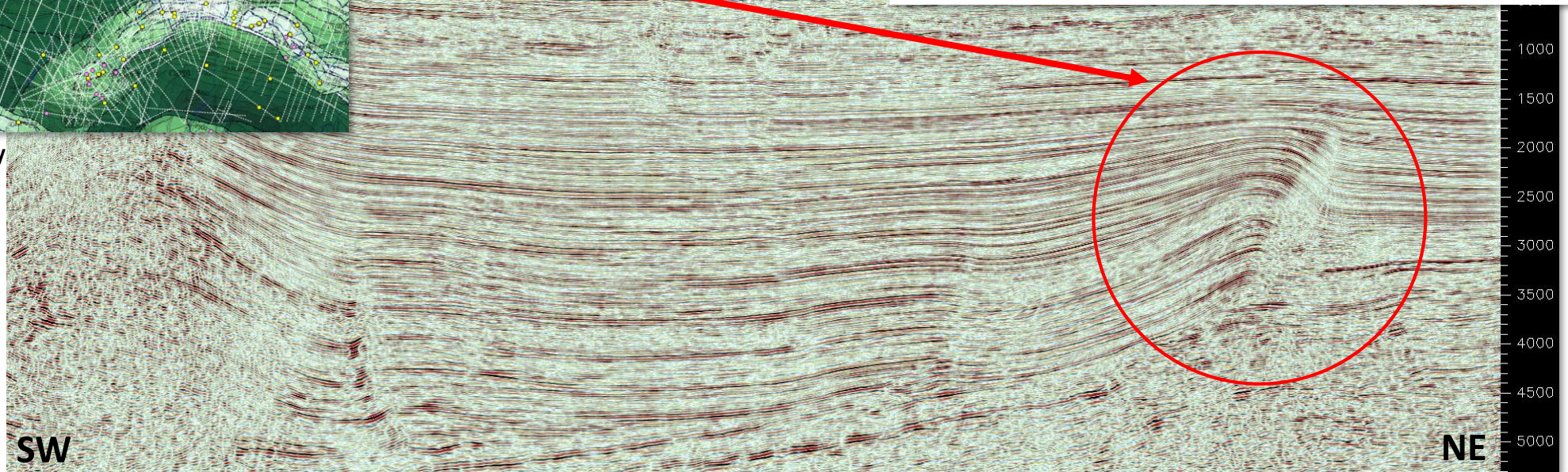
Minor thrusts are not always mapped
(e.g. Solarolo-Piadena thrust)

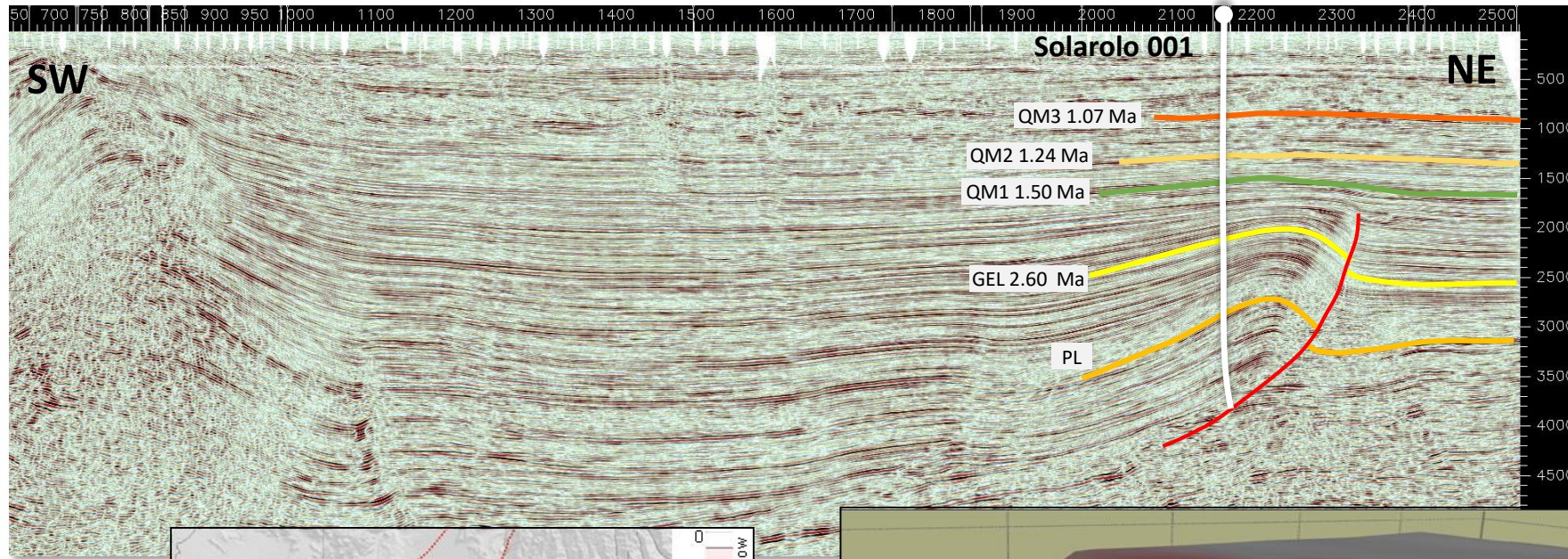
Ital. J. Geosci., Vol. 135, No. 3 (2016), pp. 000-000, 9 figs. (doi: 10.3301/IJG.2015.17)
© Società Geologica Italiana, Roma 2016

**Coupling sedimentation and tectonic control:
Pleistocene evolution of the central Po Basin**

FRANCESCO EMANUELE MAESANO (*) & CHIARA D'AMBROGI (*)

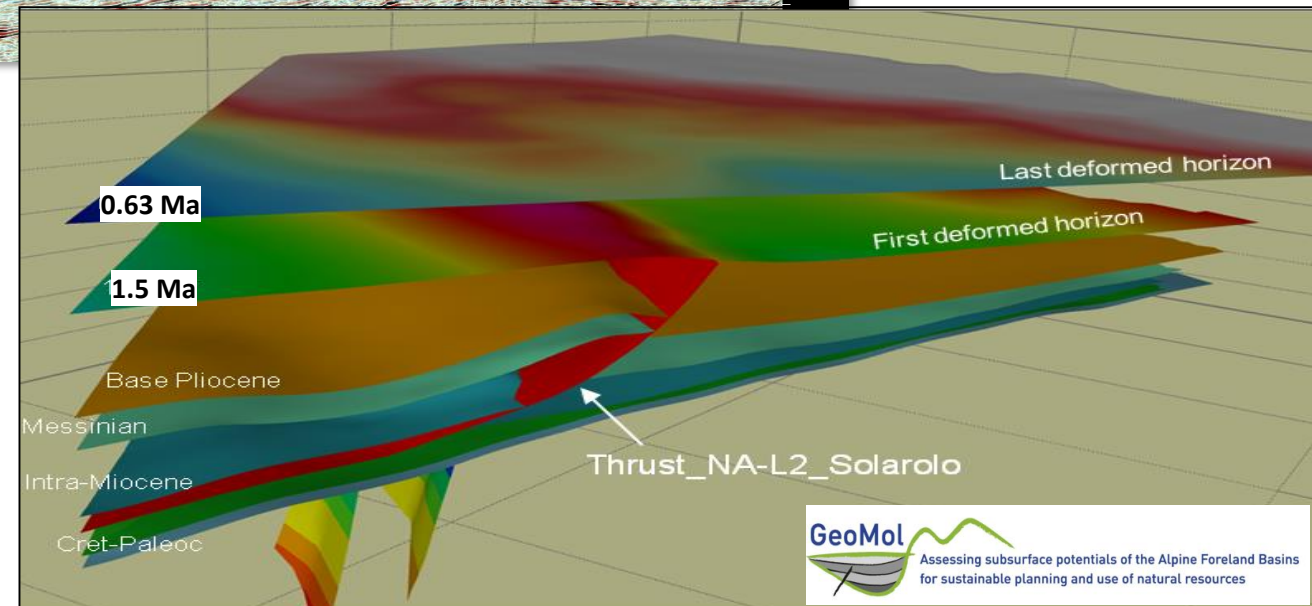
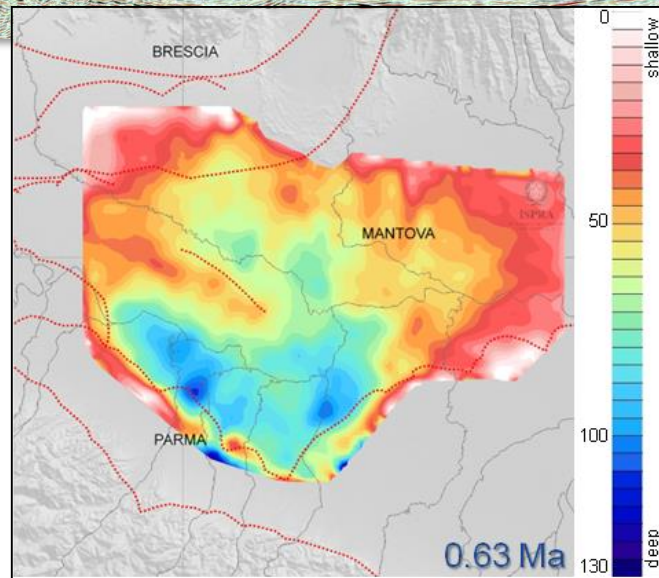
**Structural Model of Italy
Base of Pliocene**





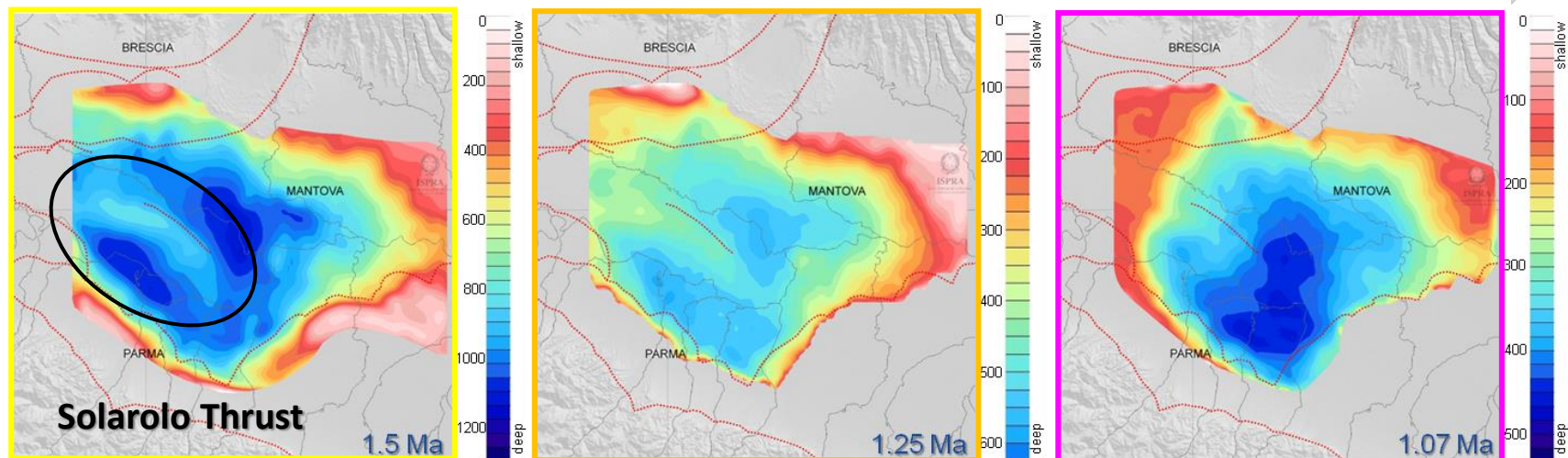
✓ età di attivazione

✓ definizione della deformazione in 3D

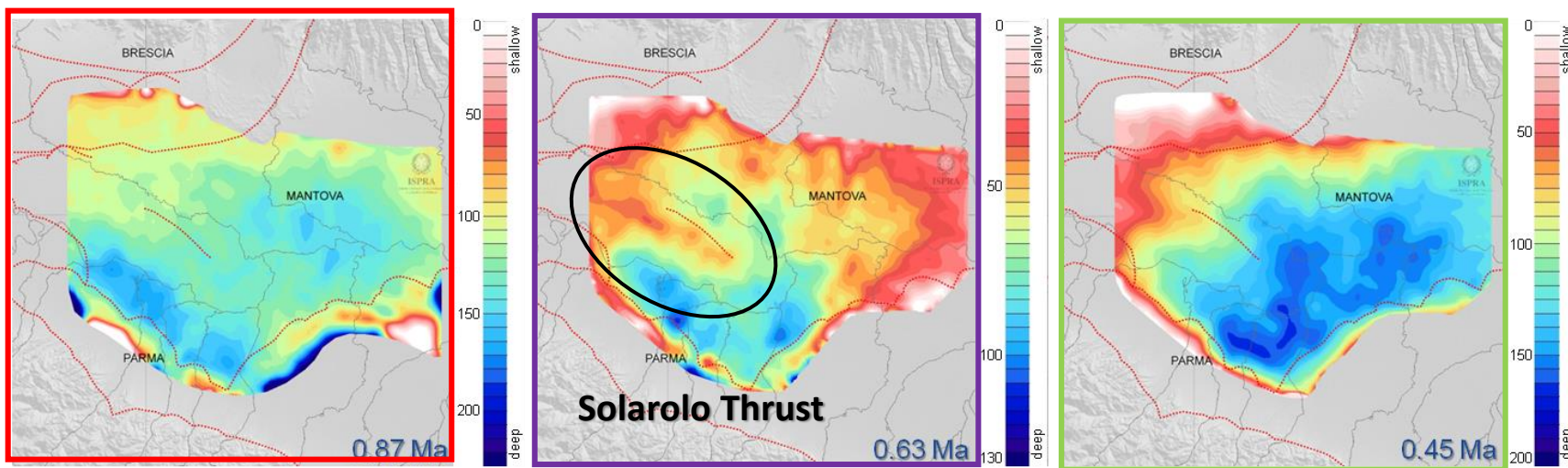


Massimizzare le informazioni geologiche

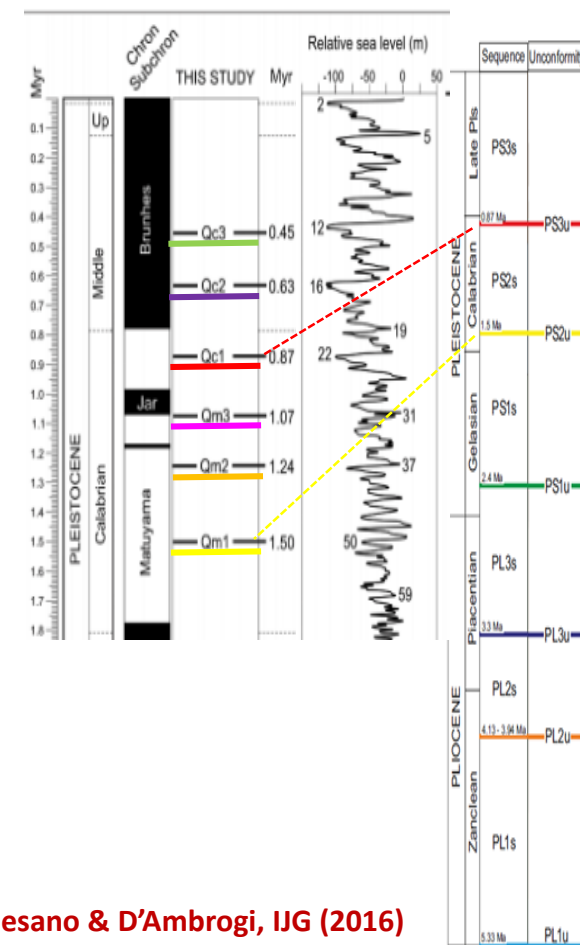
MIDDLE PLEISTOCENE



- ✓ identificazione strutture elusive
- ✓ vincoli alla storia deformativa

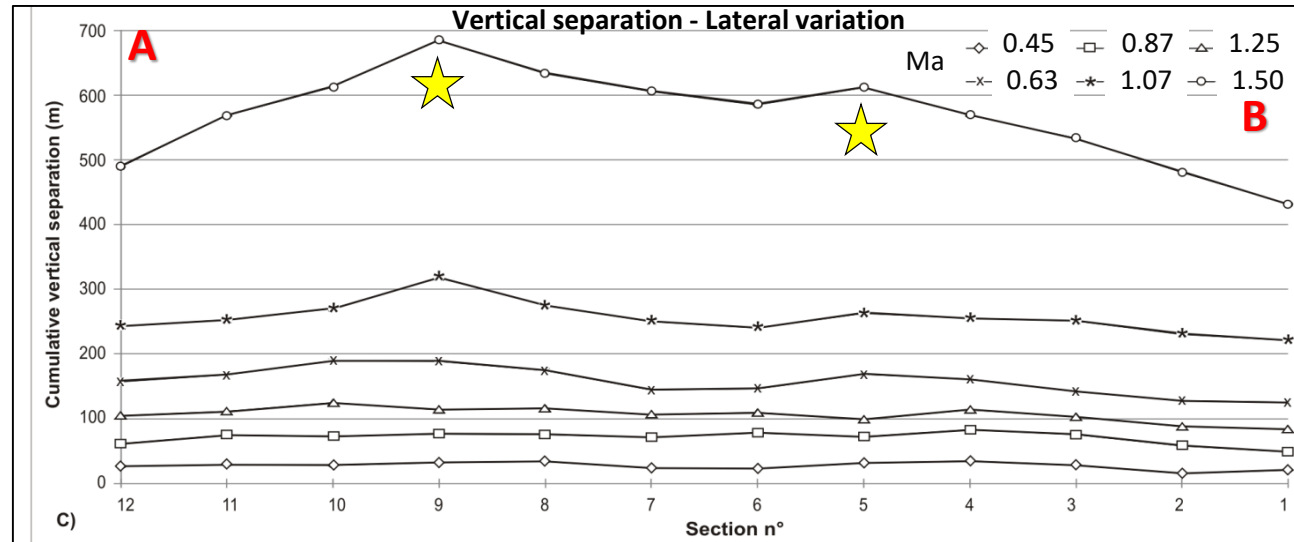
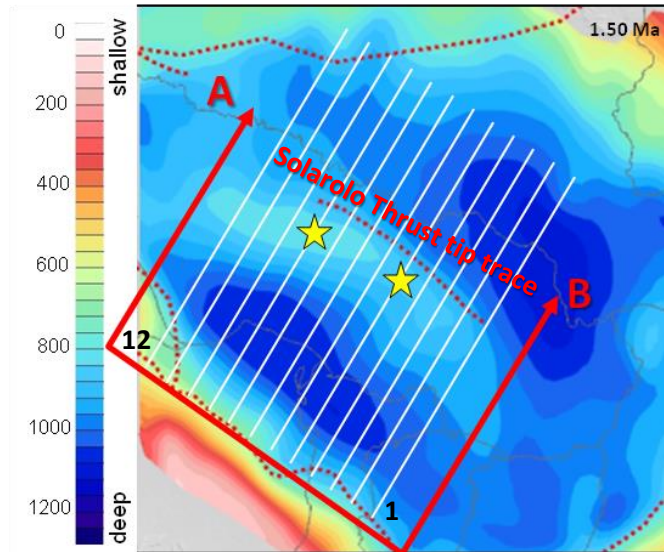


UPPER PLEISTOCENE

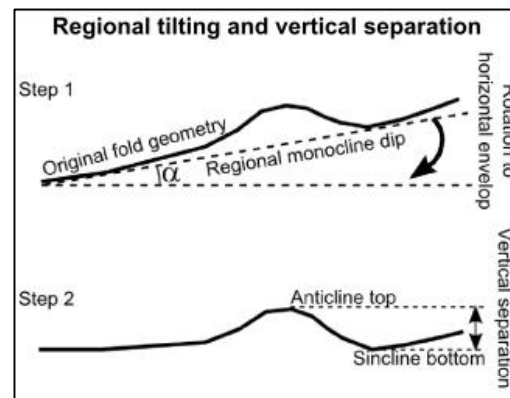
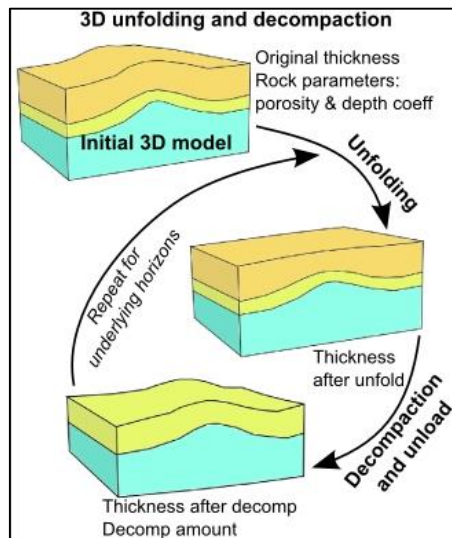


Maesano & D'Ambrogio, IJG (2016)

Quantificare la deformazione

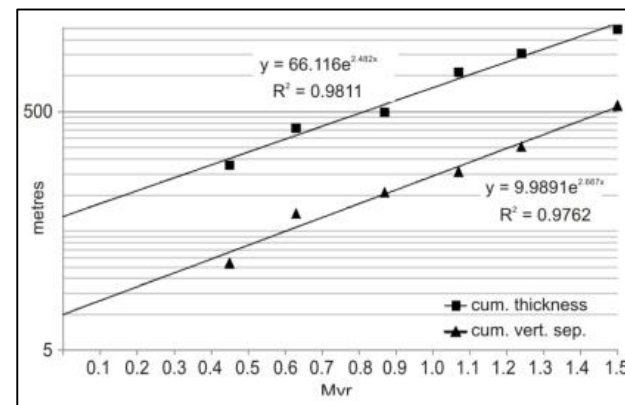


✓ Metodo per la quantificazione della deformazione (anche in bacini molto subsidenti)



Maesano & D'Ambrogio, IJG (2016)

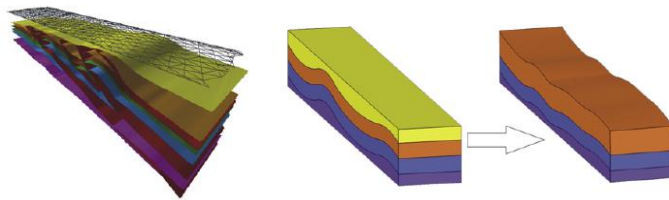
Sedimentation vs uplift rate



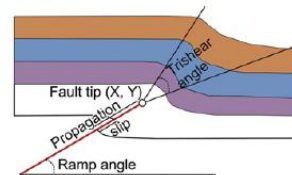
	sedim rate (mm/yr)	uplift rate (mm/yr)
Qc3-DEM	0.40 ± 0.05	0.06 ± 0.05
Qc2-Qc3	1.04 ± 0.17	0.24 ± 0.12
Qc1-Qc2	0.54 ± 0.11	0.15 ± 0.09
Qm3-Qc1	2.91 ± 0.25 #	0.26 ± 0.11
Qm2-Qm3	2.71 ± 0.28 #	0.58 ± 0.15
Qm1-Qm2	3.59 ± 0.21	1.20 ± 0.12

The sedimentation rates are calculated for the Piadena area

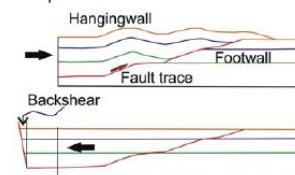
Quantificare la deformazione



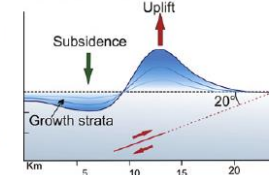
Fault-propagation folded horizons: Trishear



Dislocated horizons: Fault parallel flow



Shallow surfaces: Dislocation modeling



- ✓ slip rate differenziale e di lungo termine
- ✓ tempistica della deformazione
- ✓ presenza di strutture fuori sequenza

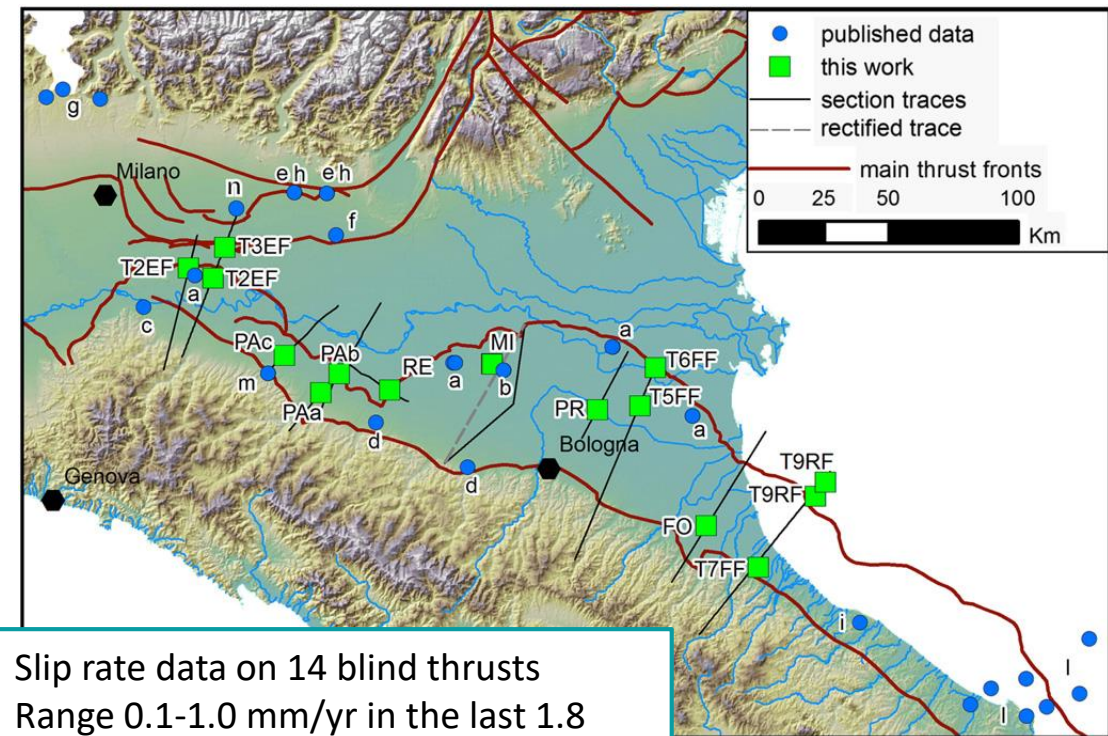
3D models

3D decompaction

Restoration algorithms

Slip rates calculated in this study. Method: FPF, fault parallel flow; TR, trishear; DM, dislocation modeling. The column DISS refers to the ID number of the DISS database (DISS Working Group, 2010) to which the analyzed structures can be ascribed.

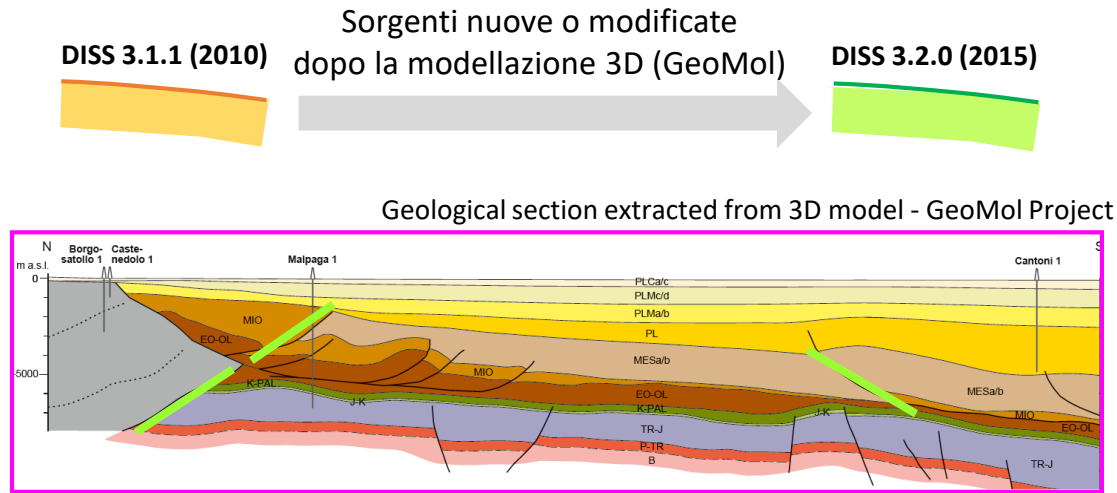
Section	Structure	Lat. N	Lon. E	Age interval Myr (min-max)		Total slip m	Slip rate mm/yr	Uncertainty mm/yr	Relative uncertainties	Method	DISS source
1	T2EF	45.215	9.598	0	1.81	212	0.12	0.03	28%	FPF	ITCS044
1	T2EF	45.215	9.598	1.81	5.3	3751	1.07	0.02	2%	FPF	ITCS044
2	T2EF	45.179	9.718	0	1.81	916	0.51	0.03	7%	FPF-TR	ITCS044
2	T2EF	45.179	9.718	1.81	2.59	450	0.56	0.08	13%	TR	ITCS044
2	T2EF	45.179	9.718	2.59	3.6	253	0.25	0.06	24%	FPF	ITCS044
2	T3EF	45.285	9.777	0	1.81	340	0.19	0.03	18%	TR	n.a.
3	T5FF	44.703	11.794	0	1.81	930	0.52	0.03	6%	TR	ITCS012
3	T5FF	44.703	11.794	1.81	3.6	729	0.41	0.03	8%	FPF	ITCS012
3	T6FF	44.833	11.875	0	1.81	750	0.42	0.03	8%	TR	ITCS050
4	T7RF	44.127	12.338	0	1.81	1875	1.04	0.03	3%	TR	ITCS039
4	T9RF in	44.366	12.628	0	1.81	451	0.25	0.03	13%	FPF	n.a.
4	T9RF in	44.366	12.628	1.81	2.59	500	0.63	0.08	12%	FPF	n.a.
4	T9RF in	44.366	12.628	2.59	3.6	2227	2.23	0.06	3%	FPF	n.a.
4	T9RF out	44.412	12.680	0	1.81	205	0.11	0.03	29%	FPF	n.a.
4	T9RF out	44.412	12.680	1.81	2.59	786	0.98	0.08	8%	FPF	n.a.
4	T9RF out	44.412	12.680	2.59	3.6	434	0.43	0.06	14%	FPF	n.a.
PAa	PAa	44.776	10.239	0	0.4	121	0.30	0.19	62%	DM	ITCS009
PAa	PAa	44.776	10.239	0.4	0.82	167	0.40	0.18	45%	DM	ITCS009
PAa	PAa	44.776	10.239	0	0.82	288	0.35	0.18	52%	DM	ITCS009
PAb	PAb	44.841	10.331	0	0.82	214	0.26	0.06	23%	TR	ITCS009
PAc	PAc	44.907	10.065	0	0.82	180	0.22	0.06	28%	TR	ITCS009
RE	RE	44.781	10.575	0	0.82	81	0.10	0.06	62%	TR	ITCS049
MI	MI	44.864	11.077	0	0.125	118	0.94	0.60	64%	DM	ITCS051
MI	MI	44.864	11.077	0.125	0.4	227	0.83	0.27	33%	DM	ITCS051
MI	MI	44.864	11.077	0	0.4	345	0.86	0.38	43%	DM	ITCS051
MI	MI	44.864	11.077	0.4	0.82	287	0.68	0.18	66%	DM	ITCS051
MI	MI	44.864	11.077	0	0.82	632	0.77	0.27	36%	DM	ITCS051
PR	PR	44.695	11.587	0	0.82	235	0.29	0.09	32%	DM	ITCS012
FO	FO	44.278	12.094	0	0.82	200	0.24	0.09	38%	DM	ITCS011



Slip rate data on 14 blind thrusts
Range 0.1-1.0 mm/yr in the last 1.8 Ma

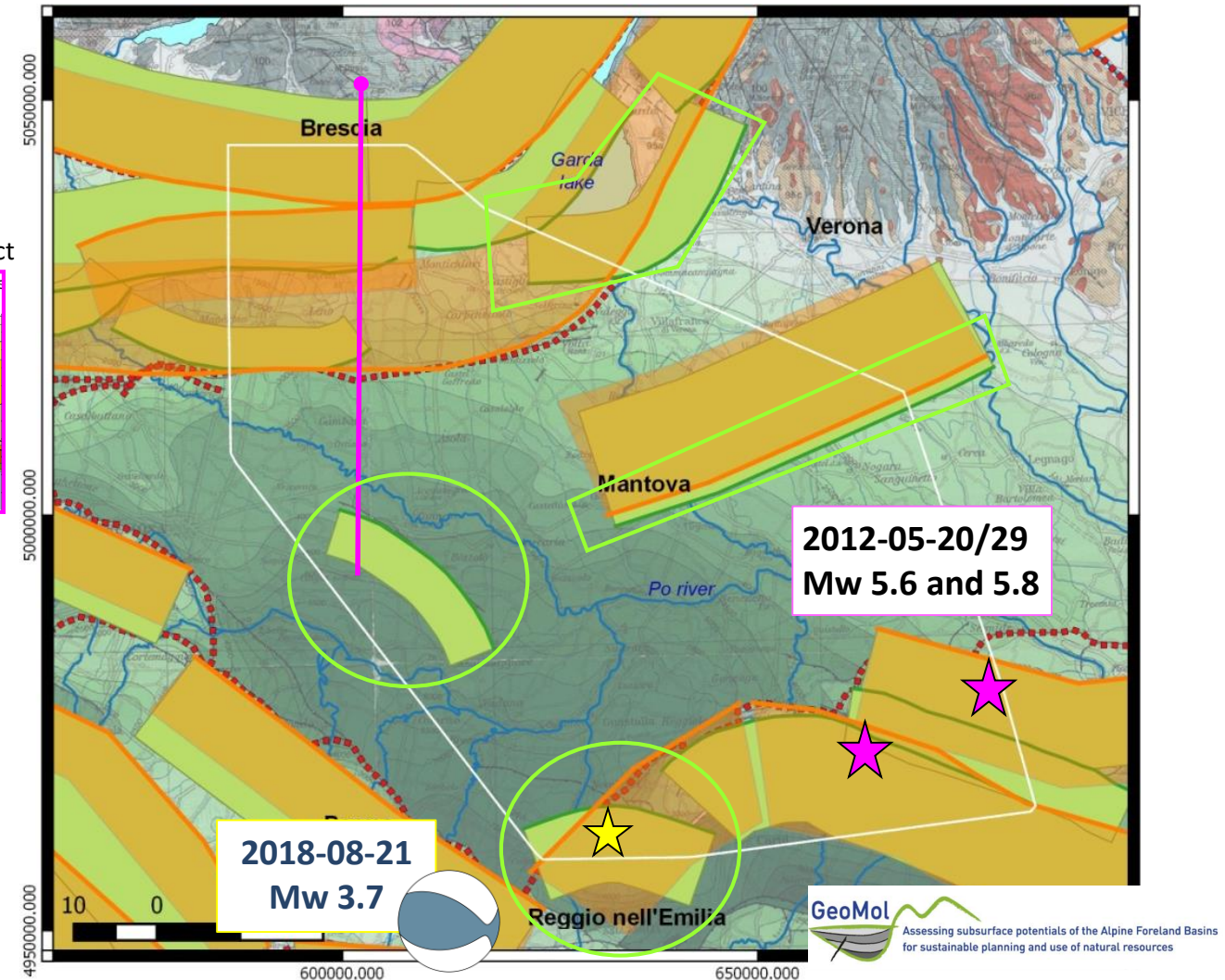
Maesano et al., Tectonophysics (2015)

Faglie 3D e DISS – Italian Database of potential Seismogenic Sources for earthquakes larger than M 5.5 (INGV)



Miglioramenti dopo la modellazione 3D

- ✓ migliore definizione livelli di scollamento
- ✓ nuove sorgenti sismogeniche
- ✓ modifica della geometria di sorgenti (geometria, profondità)

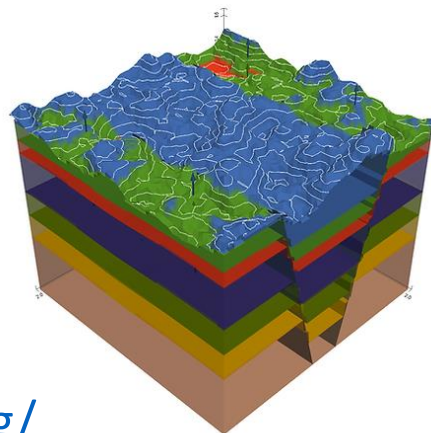


GemPy

Open-source 3D geological modeling

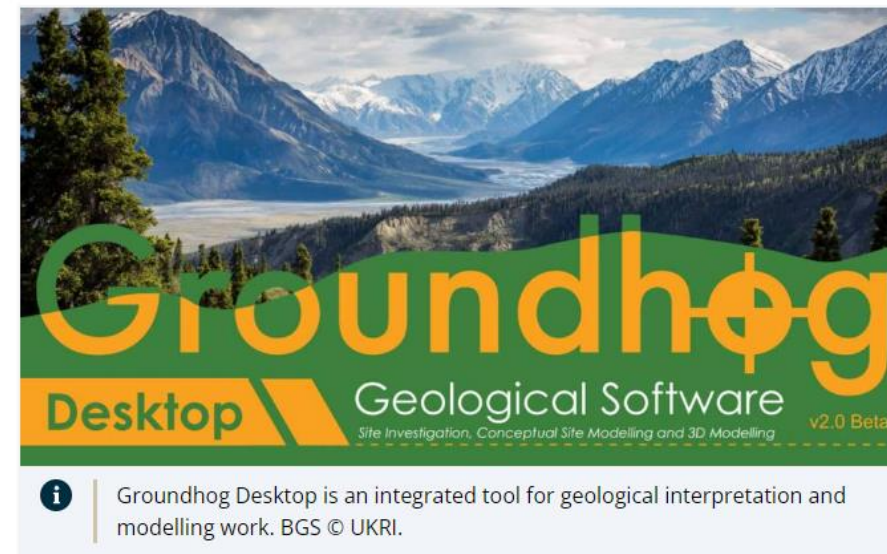
GemPy is a tool for generating **3D structural geological models** in **Python**. As such, it enables you to create complex combinations of stratigraphical and structural features such as **folds, faults, and unconformities**. It was furthermore designed to enable **probabilistic modeling** to address parameter and model uncertainties.

Best of all: GemPy is completely **free** and **open-source**!



<https://www.gempy.org/>

Modellazione strutturale



<https://www.bgs.ac.uk/technologies/software/>

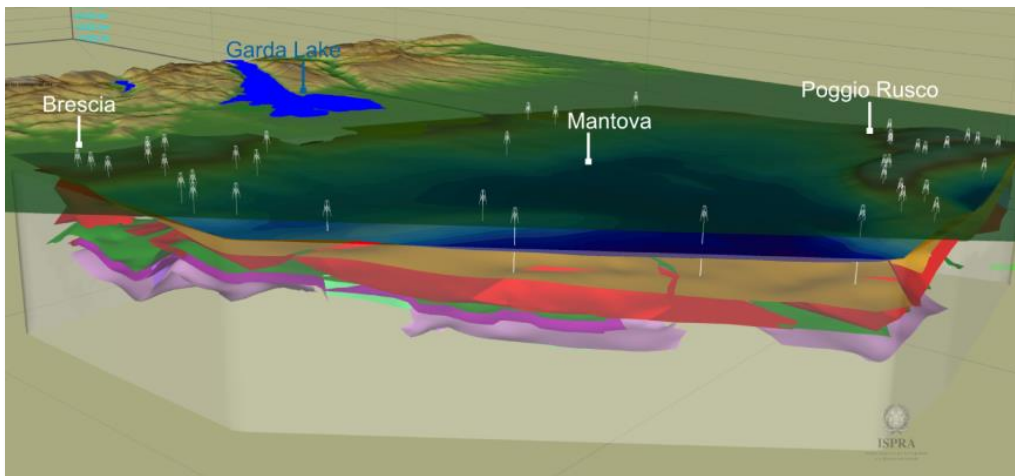
Dati di pozzo

Più molti altri software «commerciali» e estensioni GIS

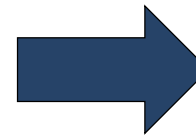
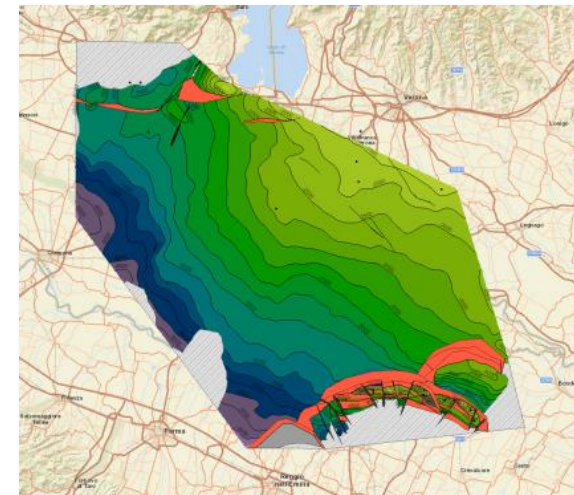
PNRR Geosciences IR – sviluppo di un tool di modellazione gratuito «italiano»

Diffusione dei modelli e loro utilizzo

Modello 3D



Mappe derivate dal modello 3D



In fase di sviluppo



Visualizzatore 3D

Geopackage

MapViewer

WMS

Buona modellazione

