7th EUropean Congress
on REgional GEOscientific Cartography
and Information Systems
Sustainable Geo-Management
Bologna, 12th - 15th June, 2012

Session 9 – Seismic risk

SEISMIC MICROZONATION
OF THE GIRONA URBAN AREA (CATALONIA, NE SPAIN) FROM STATISTICAL ANALYSIS OF GEOTECHNICAL DATA

David Soler (1), David Brusi (1), Manel Zamorano (1), Xavier Goula (2), Sara Figueras (2), Albert Macau (2), Andreu Martí (2) and Miquel Vilà (2)

(1) Centre de Geologia i Cartografia Ambiental GEOCAMB, TECNIO, Universitat de Girona

(2) IGC Institut Geològic de Catalunya

Index

1. Introduction

· At a local level, a first approach to the potential effects of damaging earthquakes is the estimation of ground movements due to amplification of the seismic vibrations (**“soil effect”**).

· Soil dynamic parameters can be obtained by **correlation** from geological and geotechnical data, according to equivalences defined in national seismic normatives (e.g.: Spanish Seismic Building Code, NCSE-02).

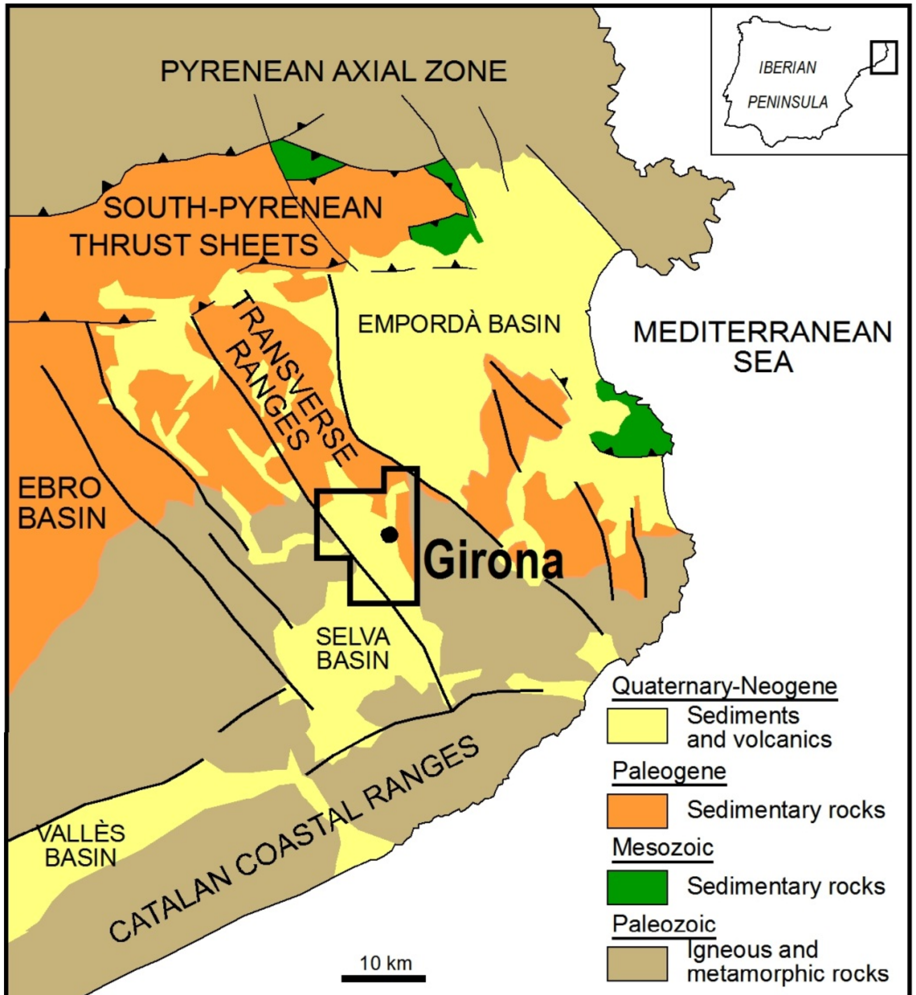
· In urban areas expanded and developed during the last decades, **ground investigation reports** are abundant and represent a valuable source of geolocated variables with seismic significance.

· Basic level **microzonation** of the Girona urban area has been conducted by:

i. statistical processing of a geological and geotechnical **database**,
ii. quantitative **seismic characterization** of the soil and rock units,
iii. site specific determination of **soil coefficients** influencing the local seismic response, and
iv. cartographic delineation of **isoamplification zones** within the urban framework.

This work is included in the SISPyr project, program INTERREG IV A

2. Seismotectonic and geological setting



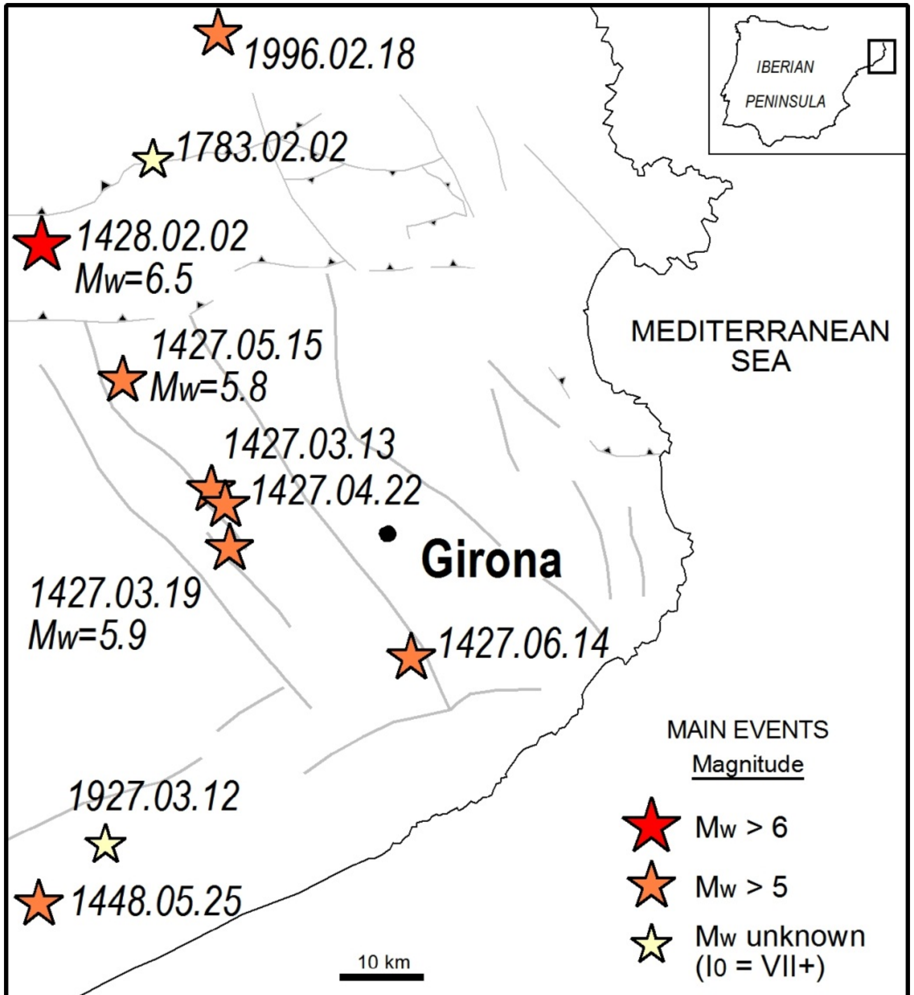
· Eastern end of the **Pyrenees** and the **Catalan Coastal Ranges**

· **Neogene grabens** filled with sediments and basic volcanics

· Plioquaternary NW-SE trending **normal faults**

· Some of them are **seismogenic sources**

Historical and instrumental seismicity



(www.igc.cat)

· Moderate periodical seismicity

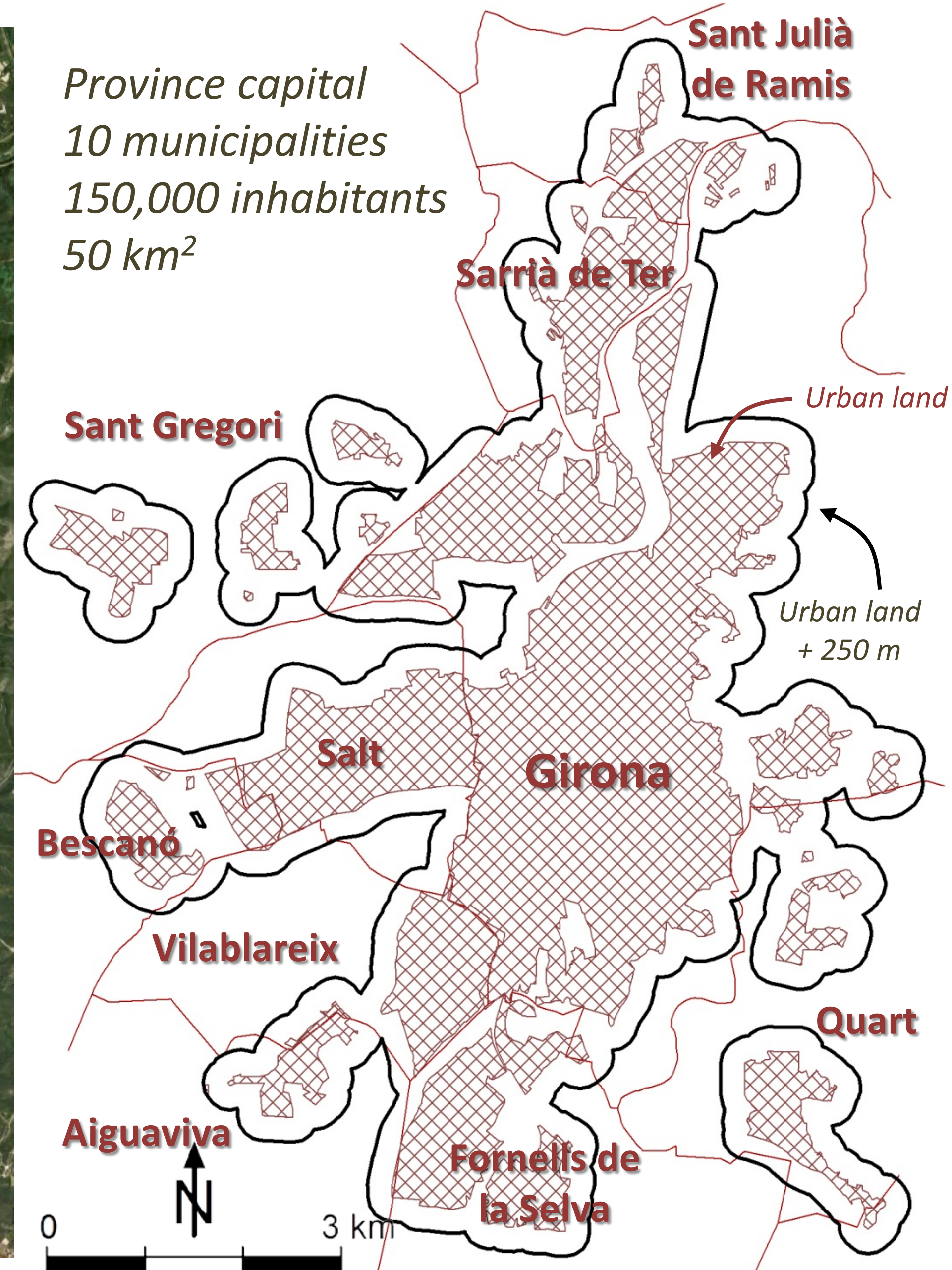
· Low rates of strong events up to Mw=6.3-6.8 (475-year return period)

· Estimated peak ground acceleration (**PGA**) for Girona:

0.070 g – 0.090 g (NCSE-02)
0.077 g-0.102 g (Secanell *et al.*, 2008)
0.140 g (Mezcua *et al.*, 2011)

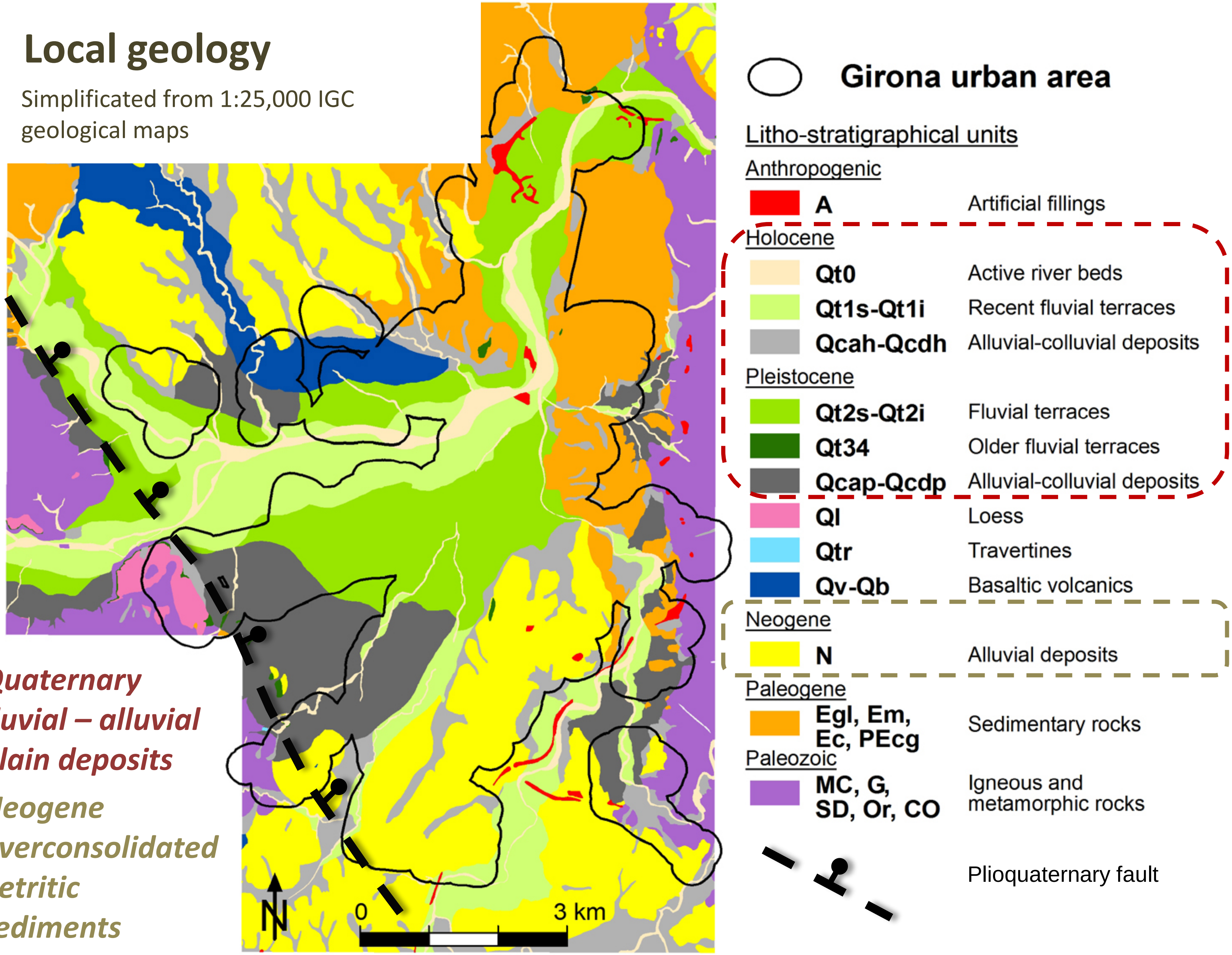
Girona urban area

Province capital
10 municipalities
150,000 inhabitants
50 km²



Local geology

Simplificated from 1:25,000 IGC geological maps



Quaternary fluvial – alluvial plain deposits

Neogene overconsolidated detritic sediments

3. Geotechnical database processing

· Database of geological and geotechnical investigation reports compiled by GEOCAMB (University of Girona).

· Typologies of prospection points included:

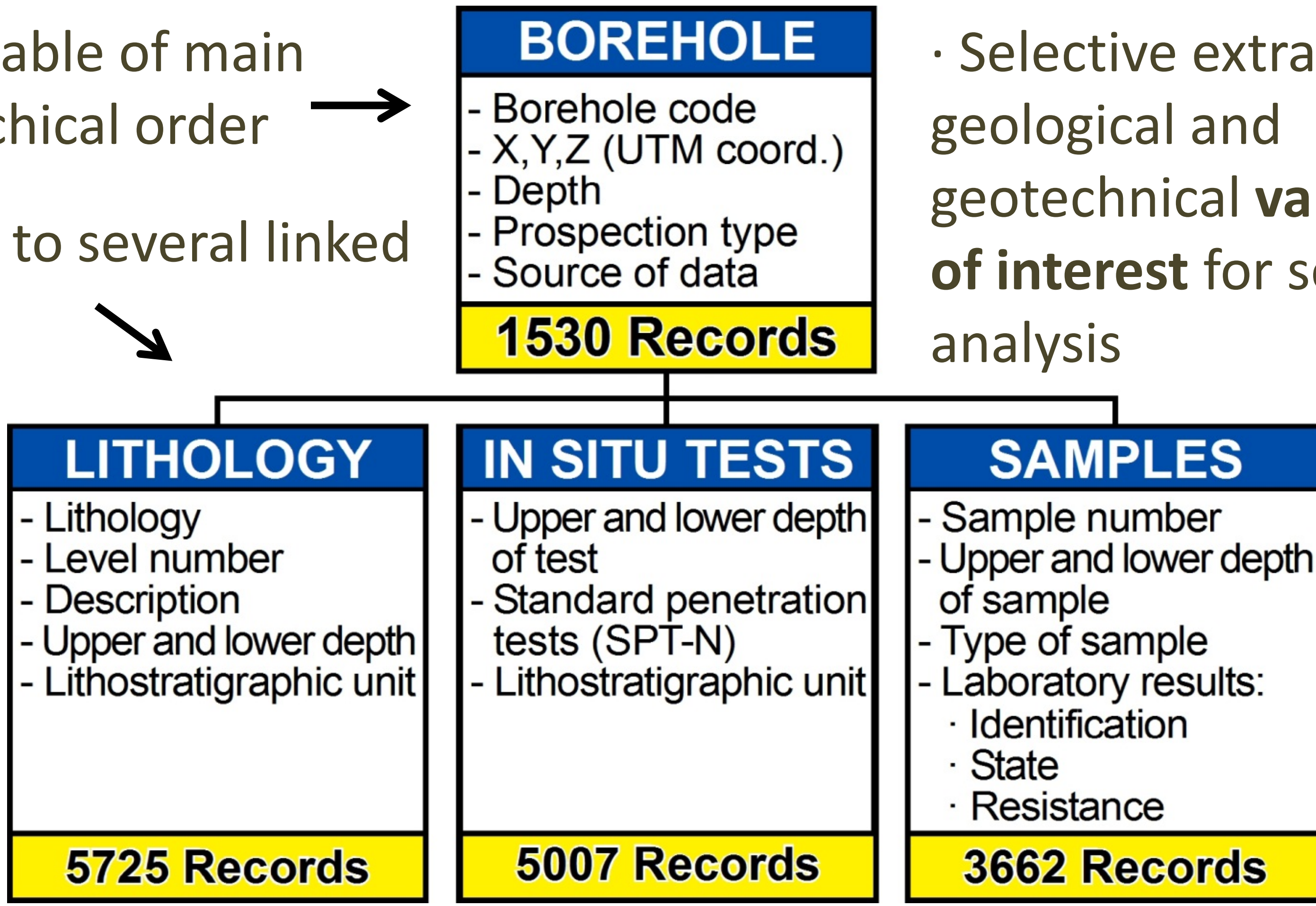
- **Boreholes** (85% out of total)
- Dynamic probing tests (DPSH)
- Excavations
- Wells
- Natural outcrops

Structure of the database

· One table of main hierarchical order

· None to several linked tables

· Selective extraction of geological and geotechnical **variables of interest** for seismic analysis



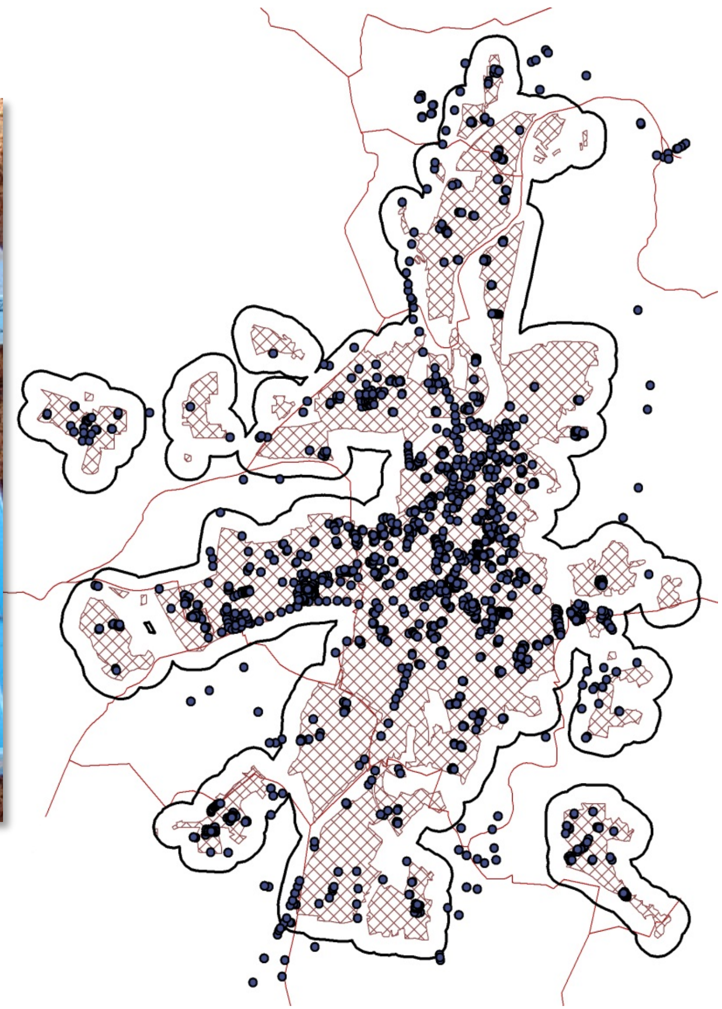
Prospection points

Cohesive material (Qt2s)

SPT cores

Unaltered soil sample

Granular material (Qt2i)



Statistical synthesis of geotechnical parameters

· Carried out for each one of the lithostratigraphical **soil units** (Quaternary, Neogene and some altered rock units).

· Summarized parameters:

i) In situ tests:

- Standard penetration test blow count, **SPT-N**
- Dynamic Probing Super Heavy penetration test, DPSH-N

ii) Laboratory tests on soil samples:

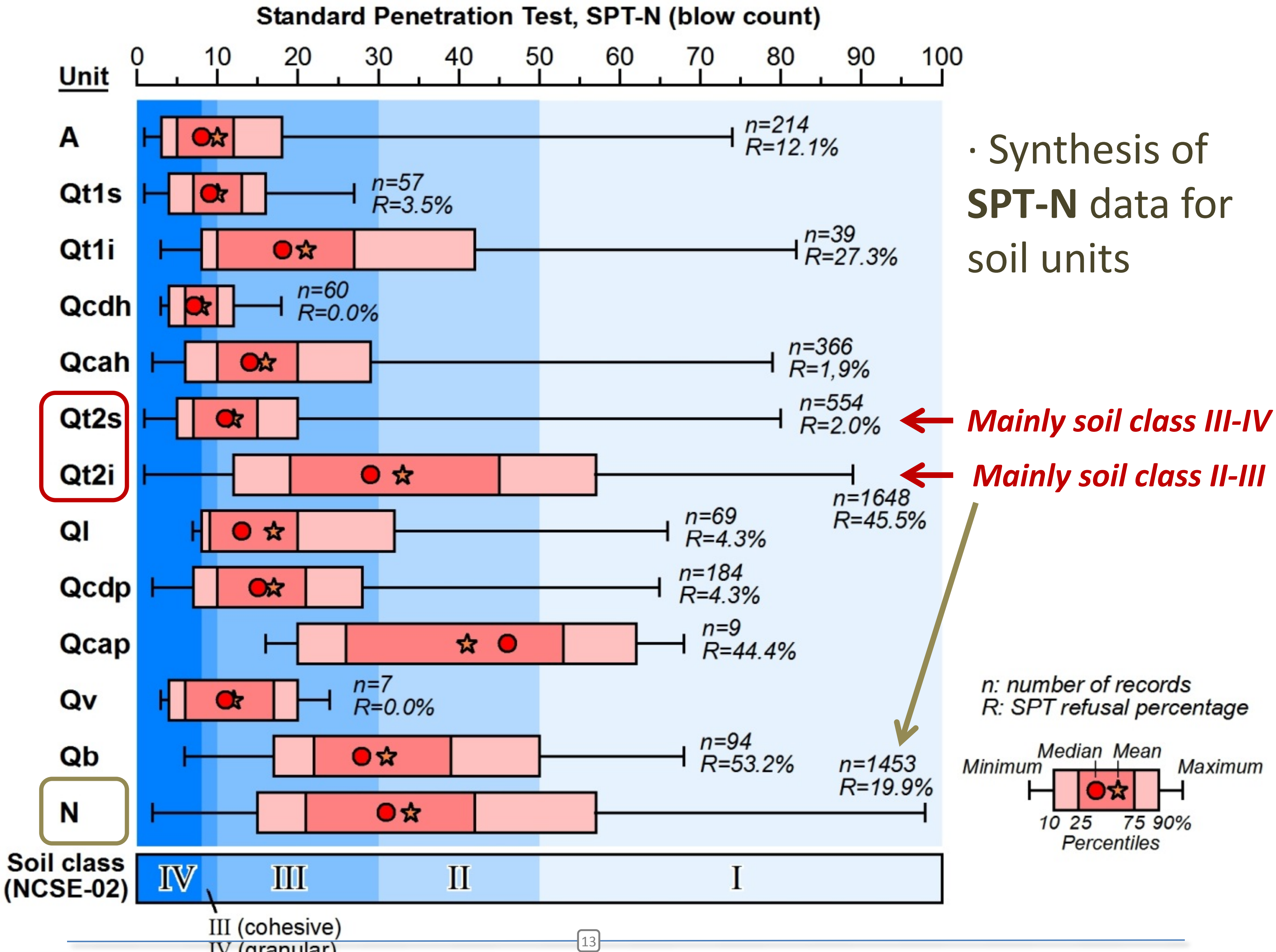
- Unconfined shear strength, **Qu**
- Granulometric percentages, especially **fine content**
- Atterberg limits and Casagrande plasticity charts
- Dry-wet density and natural humidity content

- **NCSE-02** sets direct correlation of SPT-N and Qu with:

  - Seismic **soil class**
  - Soil coefficient **C**
  - Shear wave velocities, **Vs**

Inferred after code definitions about compactness of granular materials and consistency of cohesive materials, by comparison to values published in the geotechnical literature

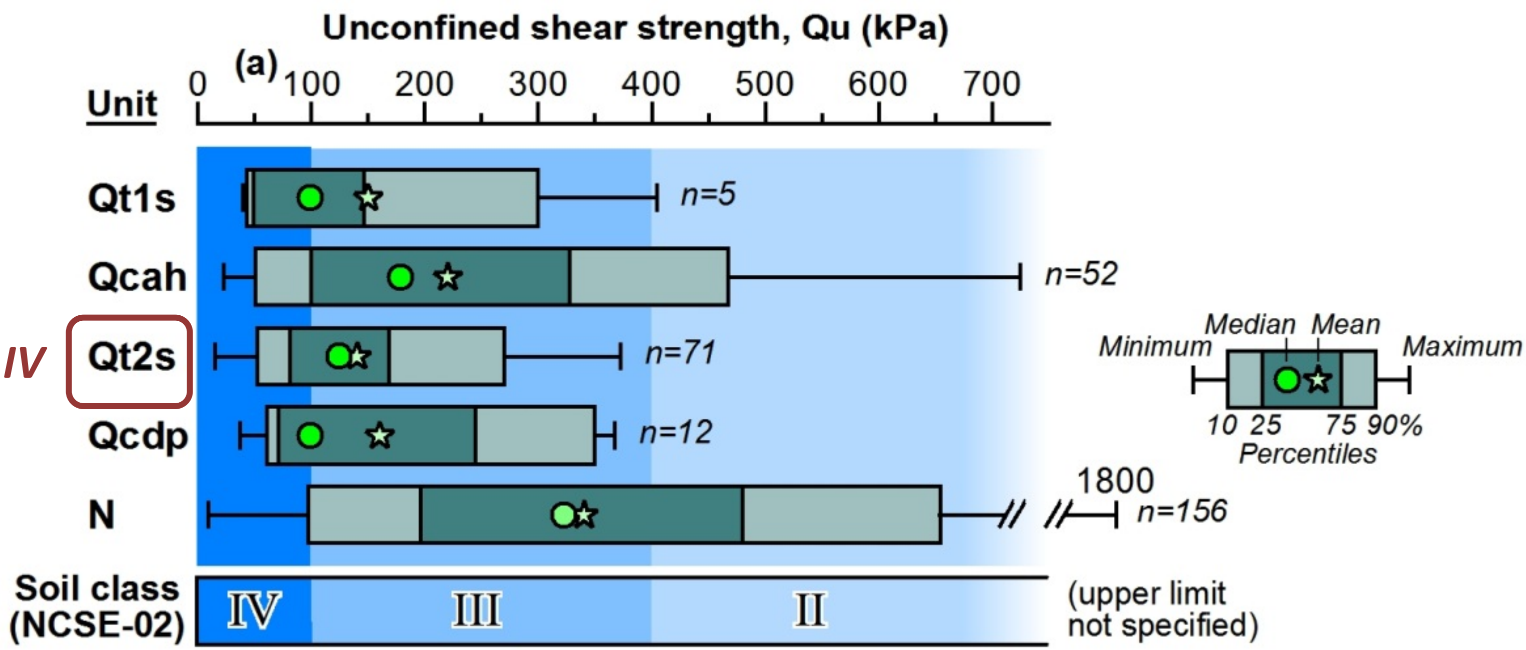
Seismic soil class	Soil coefficient C	Vs (ms^{-1})	Rock	Granular soil	Cohesive soil	
				SPT-N	SPT-N	Qu (kPa)
I	1.0	> 750	Unaltered	> 50	-	-
II	1.3	400 - 750	Fractured	31 - 50	> 30	> 400
III	1.6	200 - 400	-	11 - 30	8 - 30	100 - 400
IV	2.0	< 200	-	0 - 10	0 - 7	0 - 100



· Synthesis of **SPT-N** data for soil units

· Synthesis of **Qu** data for cohesive soil units

Soil class III - IV



4. Seismic parameterization of soil and rock units

· Soil coefficient **C** calculated by two parallel ways for **each unit**:

- Based on SPT-N data ⟶ $C_{(SPT\text{-}N)}$
- Based on Qu data ⟶ $C_{(Qu)}$

$$[\, C_{(SPT\text{-}N)} \;\&\; C_{(Qu)} \,] = [\, n_{(I)} + (n_{(II)} \cdot 1.3) + (n_{(III)} \cdot 1.6) + (n_{(IV)} \cdot 2) \,] / n$$

	SPT-N records (Refusal excluded)						Laboratory samples resistance tests					
Unit	n	$n_{(I)}$	$n_{(II)}$	$n_{(III)}$	$n_{(IV)}$	$C_{(SPT\text{-}N)}$	n	$n_{(I)}$	$n_{(II)}$	$n_{(III)}$	$n_{(IV)}$	$C_{(Qu)}$
Qcah	359	6	25	225	103	1.68	52	0	7	33	12	1.65
Qt2s	543	3	7	393	140	1.70	71	0	0	44	27	1.75
Qt2i	898	148	279	398	73	1.44	4	0	0	4	0	1.60
N	1104	160	399	496	49	1.42	156	6	49	85	16	1.52

· A representative soil coefficient **C(R)** for all the units is derived from integrated consideration of:

- $\mathbf{C_{(SPT\text{-}N)}}$
- $\mathbf{C_{(Qu)}}$
- **Granulometric** percentages and fine content (granular/cohesive/mixed geotechnical character)
- Density, humidity, plasticity and other descriptive information

· Additionally, shear wave velocities $\mathbf{V_s}$ have been calculated for each individual SPT value by empirical equivalences (Kanai *et al.*, 1966), and then summarized by units.

$$V_s = 62\ \text{SPT-N}^{0.6}$$

Unit	Geotechnical behaviour	$C_{(SPT-N)}$	$C_{(Qu)}$	$C_{(R)}$	Vs (ms^{-1})	Assigned soil class
A	Heterogeneous	1.87	-	2.0	120 - 351	IV
Qt0	Granular	-	-	2.0	-	IV
Qt1s	Mixed	1.86	1.70	1.8	151 - 330	III - IV
Qt1i	Granular	1.62	-	1.6	216 - 584	III
Qcah	Mixed	1.68	1.65	1.7	182 - 458	III - IV
Qcdh	Mixed / Cohesive	1.93	1.73	1.8	161 - 279	III - IV
Qt2s	Mixed / Cohesive	1.70	1.75	1.8	163 - 374	III - IV
Qt2i	Granular	1.44	1.60	1.45	275 - 701	II - III
Qt34	Mixed	1.30	1.45	1.3	355 - 676	II
Qcap	Mixed / Granular	1.30	1.60	1.6	372 - 736	III
Qcdp	Mixed / Cohesive	1.68	1.80	1.7	199 - 453	III - IV
Ql	Mixed	1.70	-	1.8	380 - 679	III - IV
Qtr	Rock / Mixed	-	-	1.3 / 2.0	-	II / IV
Qv	Granular	1.77	-	1.8	146 - 378	III - IV
Qb	Granular / Rock	1.47	-	1.45 / 1.15	343 - 648	II - III / I - II
N	Mixed	1.42	1.52	1.45	315 - 701	II - III
Em	Rock / Cohesive	1.36	1.00	1.0 / 1.15 - 1.3	-	I / I - II
PEcg	Rock / Cohesive	1.19	1.27	1.0 / 1.15 - 1.3	-	I / I - II
Egl, Ec	Rock	-	-	1.0	-	I
MC, G, SD, Or, CO	Rock	-	-	1.0	-	I

5. Site soil amplification (NCSE-02)

· Seismic calculus acceleration $\mathbf{a_c}$ is:

$$a_c = S \cdot \rho \cdot PGA$$

S: Soil amplification factor
ρ: non-dimensional risk coefficient
(1.0-1.3 for normal-special importance buildings)

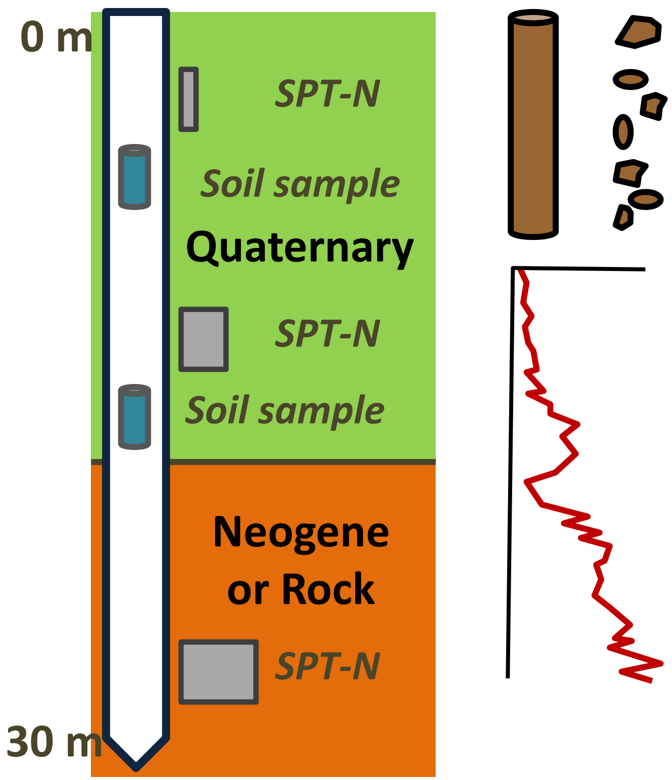
· Since PGA (Girona area) is 0.07-0.09, then $S_{(PGA<0.1)} = C / 1.25$

· Soil coefficient **C** is a good indicator in estimation of soil effect:

$$C = (\sum C_i \cdot e_i) / 30$$

$\left.\begin{array}{l}\mathbf{C_i}\text{: Soil coefficient C} \\ \mathbf{e_i}\text{: individual thickness}\end{array}\right\}$ **for all the soil class layers in the first 30 m from the surface**

· Database: great **heterogeneity** in the amount, precision and confidence of **available data** among the prospection points.



- Borehole:

  30 m?
  Pre-Quaternary substratum?
  Continuous/discontinuous core?
  Representativeness of the core?
  Dynamic probing log? (no core)

- Lithology levels:

  Valid SPT-N data? (not refusal)
  Lab. resistance tests on unaltered soil samples?

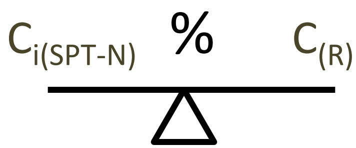
· Need of systematization in the process to obtain **C**

1,530 boreholes: many boreholes with few or poorly constrained data

C_i	e_i
C_1	e_1
C_2	e_2
C_3	e_3
.	.
.	.
.	.
C_n	e_n

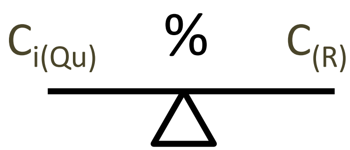
· Standardized C_i calculation method by weighted contribution of $\mathbf{C_{i(SPT\text{-}N)}}$, $\mathbf{C_{i(Qu)}}$, $\mathbf{C_{(R)}}$ (**25** typological cases)

i) After in situ penetration tests:



Cases **N1** to **N8**

ii) After laboratory resistance tests:



Cases **M1** to **M6**

iii) From extrapolation: $C_{(R)}$

· Rock Cases **R1** to **R3**
· Soil Cases **S1** to **S7**
· Anthropogenic Case **A1**

· Additionally, each C_i case is attributed to a quality (confidence) index, $\mathbf{I_{qci}}$

$$I_{qc} = \left(\sum I_{qci} \cdot e_i \right) / 30$$

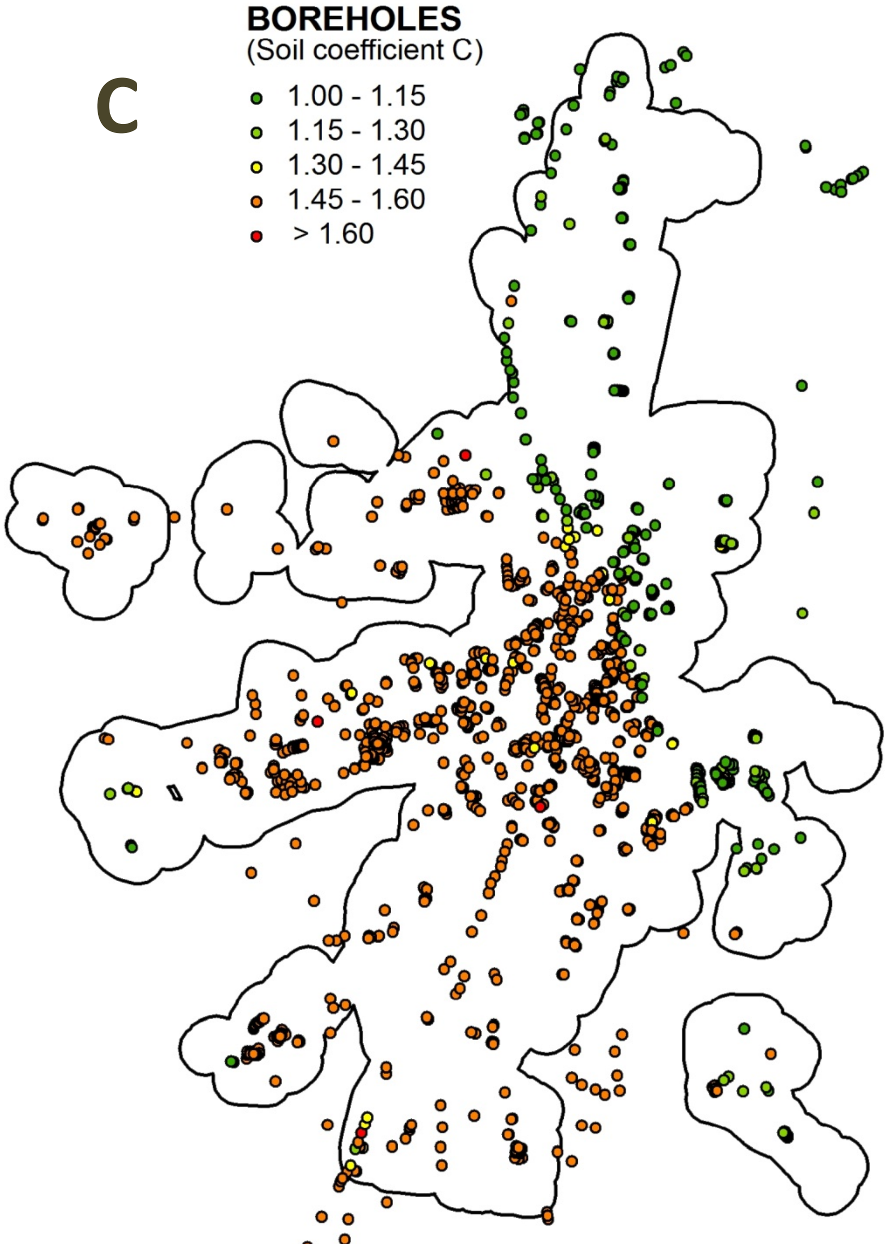
$\mathbf{I_{qci}}$: **1-4** (poor to very good C_i confidence)

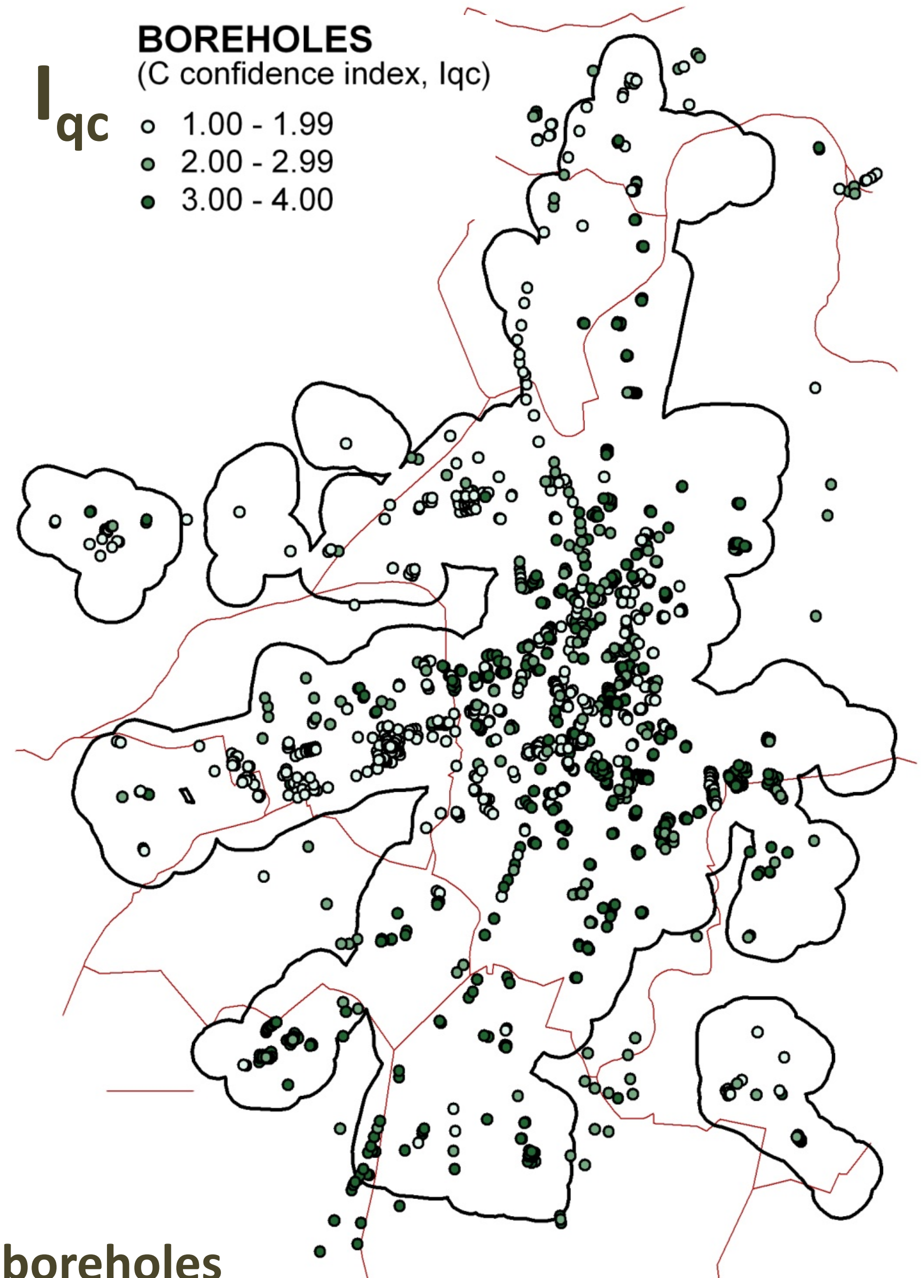
· Example of **C** and $\mathbf{I_{qc}}$ calculation for one borehole:

Unit	ei (m)	SPT-N (m)	SPT-N % ei	$Ci_{(SPT-N)}$	Qu (m)	Qu % ei	$Ci_{(Qu)}$	$C_{(R)}$	Criteria	C_i	Iqc_i
A	0.5	0	0	-	0	0	-	2.0	A1	2.0	2
Qcah	6.0	3	50	1.8	0.45	7.5	1.6	1.7	N1, M4	1.71	3.5
N	3.5	0.6	17	1.6	0	0	-	1.45	N2	1.49	3
N	20.0	-	-	-	-	-	-	1.45	S1	1.45	3

C	Iqc
1.51	3.08

Borehole reference: 200401610





1,328 boreholes

6. Basic level seismic microzonation

· C coefficient isoamplification zones

Zone A-1

Rock cropping out or covered by a thin layer of Quaternary sediments.

Zone A-2

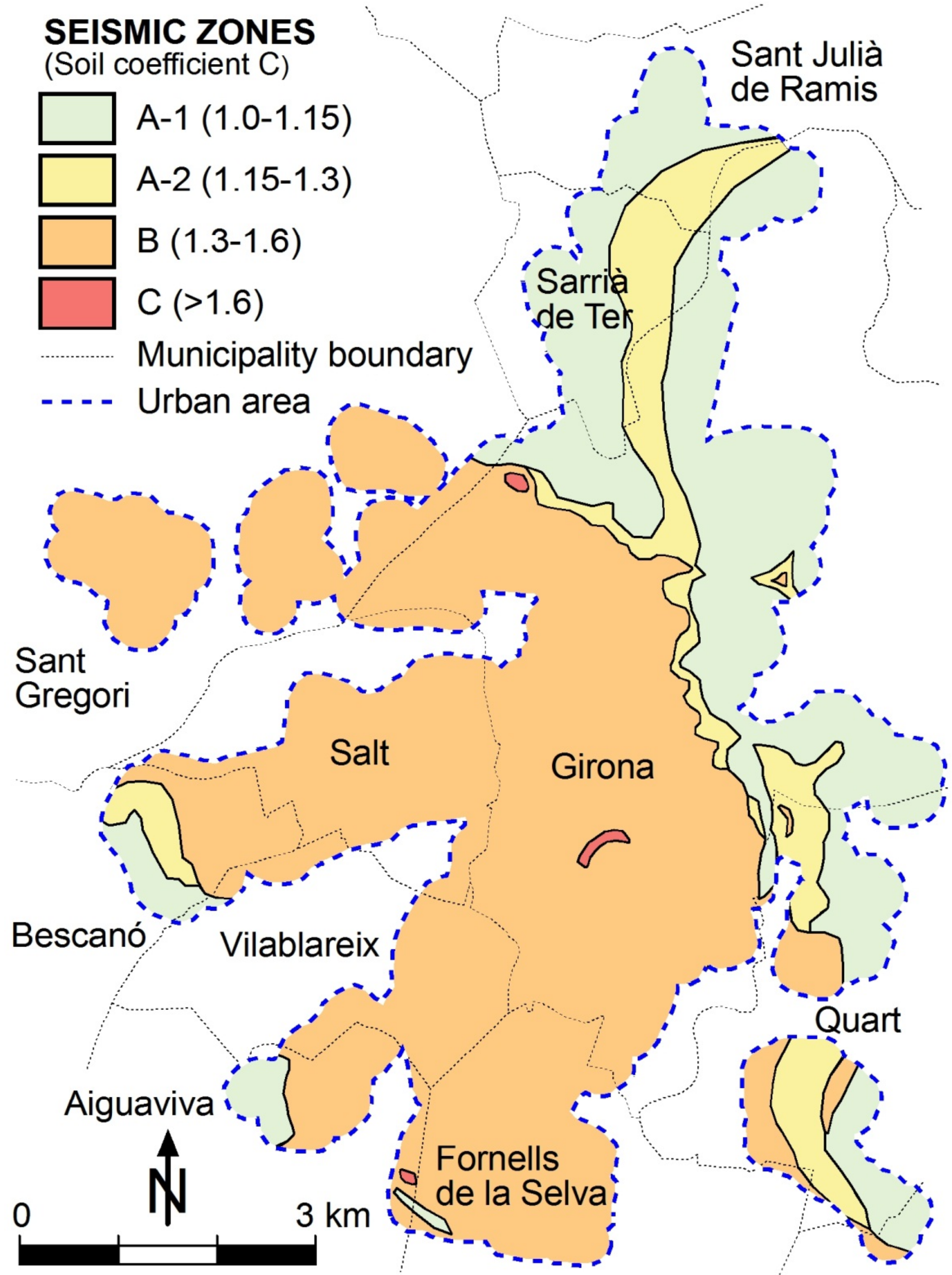
Rock overlain by 5-20 meters of low seismic quality Quaternary sediments.

Zone B

i) Neogene sediments, ii) Quaternary alluviums up to 20 m thick overlying Neogene, iii) weathered Quaternary lava flow up to 15 m thick, over Quaternary and Neogene sediments.

Zone C

Local thick, soft Quaternary alluviums on Neogene.



7. Conclusions

· **Geotechnical databases**: a valuable source of ground information for basic seismic analysis. √

· Direct correlation of geotechnical and geological characteristics to **soil dynamic parameters** by means of published equivalences (seismic building codes). √

· **Weighted contribution of seismic parameters** obtained by parallel, complementary ways allows to get standardized seismic data, instead of how much / how good available information comes out from the boreholes. √

7. Conclusions (continued)

· This methodology reveals as a good complement in the determination of **local seismic response** from other direct techniques. √

· Resulting **microzonation** sets a starting tool for more specific targets: field geophysical measurements, numerical simulations in selected emplacements, and performance of risk scenarios. √

· Data compilation, filtering and processing is time consuming. ✗

· Geotechnical investigations are usually shallow. ✗

· NCSE-02 only considers soil effect up to 30 m depth. ✗

Vi ringrazio per la vostra attenzione

Centre de Geologia i Cartografia Ambiental GEOCAMB

TECNIO

Universitat de Girona

IGC Institut Geològic de Catalunya

http://geocamb.udg.edu

http://www.igc.cat