ICGC
Institut
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de Catalunya

WI-GIM

(Wireless Sensor Network for Ground Instability Monitoring)

A2 Geological and geomorphological characterization of the Sallent site

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Índex

1 Abstract

The Estació neighborhood in Sallent is located over the old potassium mine Enrique. This zone has affected by a subsidence process over more than twenty years. In year 2009 the subsidence increase hardly and culminated with the preventive evacuation of the neighborhood and progressive demolition of buildings and houses.

Different studies done in the area have identified the mine exploitation as a cause of the general subsidence. But the presence of a karst cave located around 160m depth makes the subsidence more intense in that area.

The implementation of a wide network for ground auscultation has allowed monitoring the process of subsidence since 1997. This network consists of: i) a high-precision topographic leveling network to control the subsidence in surface; ii) rod extensometers network that monitors subsurface deformation; iii) an automatic Leica TCA Total Station to monitoring buildings movements; iv) a inclinometers network that measures the horizontal displacements on subsurface and vi) a piezometer to measure water level.

The knowledge gained during these years of the subsidence processes complemented by the huge availability of data from existing networks constitutes a solid foundation for achieving the development objectives of the project WI-GIM.

2 Introduction

In 1997 the Geological Institute of Catalonia (IGC) starts to investigate the magnitude, causes and evolution of ground movements in Sallent. These studies, which cover the entire area of influence of the old mine Enrique, were focused specifically since 2004 in Estació neighborhood as a result of the acceleration experienced by the process and the growing importance of damage in the buildings of this sector.

The objective of this paper is to perform a compilation, analysis and synthesis of available information on the process of subsidence in Sallent, focusing on extension, geometry, subsurface characterization and geological mechanisms of subsidence. All this information will be crucial for the implementation of the WI-GIM system on Estació neighborhood. Gathering information regarding to the geology and dynamics of the process, has considered the following sources: i) geological mapping, ii) stratigraphic information of wells and boreholes, iii) surface and boreholes geophysical data, iv) geotechnical in situ tests and laboratory tests, geomechanical measurements, and v) surface and underground monitoring networks, as high precision leveling, rod extensometers and inclinometers.

3 Background / Previous Works

3.1 Subsidence phenomena: process and evolution.

The Estació and Rampinya in Sallent neighborhoods are located within the former exploitation limits of the old underground potash mine. The Enrique mine operated between 1932 and 1974 at a mean depth of 260 meters. The operation was an intense method, with the opening of cameras supported by columns that represents approximately 20% of the total area. The mineral extraction was done by two wells that were connected with the surface.

During the exploitation process the mine suffered several water floods (figure 3.1) that affect the viability of the mine. In 1954, during the drainage works of one of this floods (Vinguda 1 zone), a large natural karst cavity was located. The cavity, with 28m of diameter and 110m height (figure 3.2), was partially filled with loose material from the walls and roof of the cavity. In 1955 the water flow was intercepted and pumps it out of the mine. Later the cave was used to pour salt rejection from the own mine. The mining exploitation continued northwards, leaving a protective band that borders Llobregat River. The years 1957 and 1962, under the current Rampinya neighborhoods, the mine suffered new water floods; related with the Llobregat River. The great difficulties of controlling the flooding led to the closure of Enrique Mine in 1973. During the abandonment process the mine was filled up with saturated salty water with the purpose of preventing dissolution processes and the ground subsidence caused by the mining activity (Moya et al, 1979). During mining activity and after its closure an existing monitoring network evidences the subsidence process (del Valle, 1997).

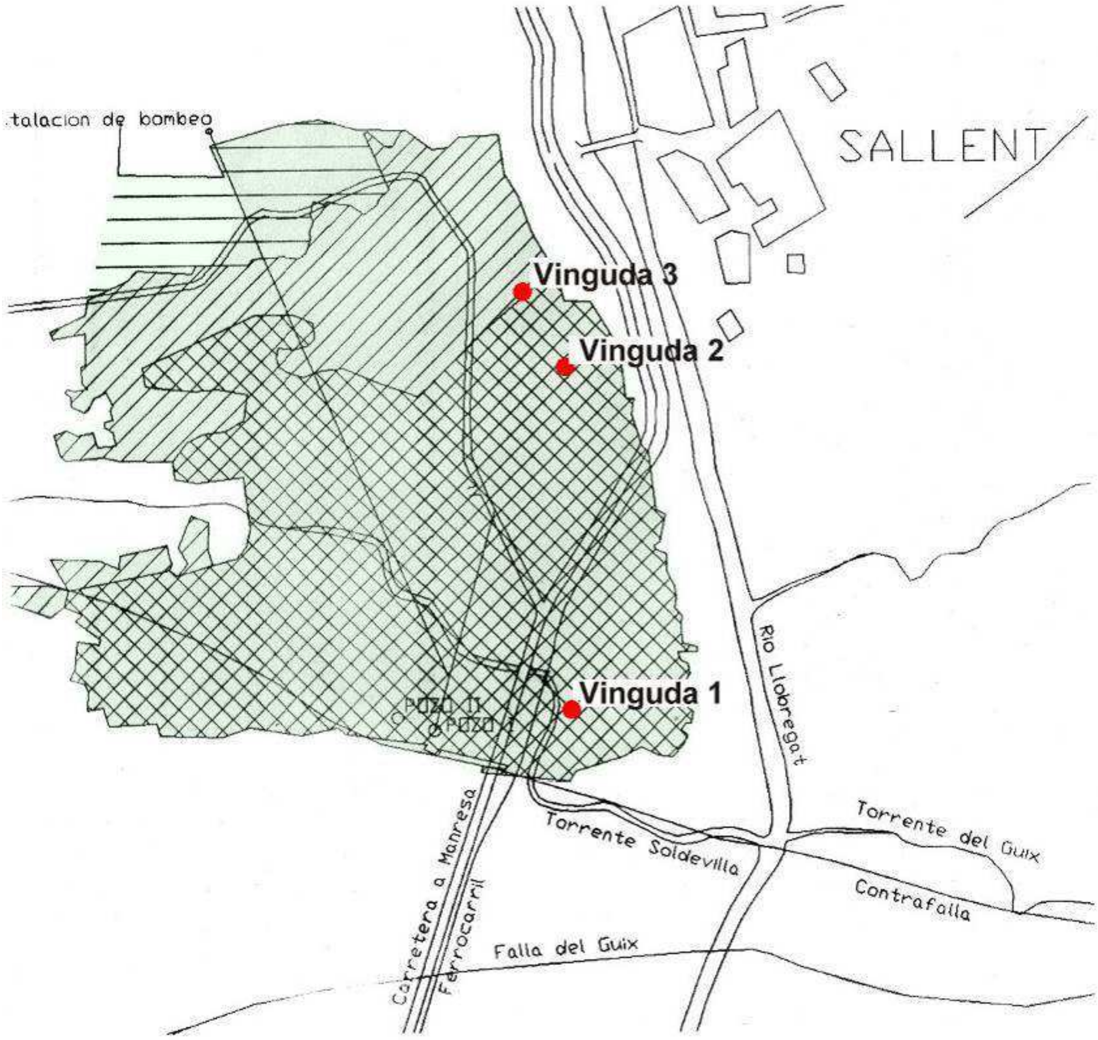

Figure 3.1. Documented location of water during the exploitation period of the mine.

But, in the 1990s damage to several buildings was reported in the Estació neighborhood and so the Catalan ministry for Territorial Planning and Public Works (DPTiOP, its initials in Catalan) started a series of studies through the Geological Institute of Catalonia (IGC) to determine the origin of the damage, monitor the phenomena and propose solutions to guarantee the population's safety.

An alert (early warning) system (Marturia et al. 2010) and an emergency plan for an organized and efficient response by the civil protection authorities have been elaborated and implemented (Procicat Sallent). The alert triggering levels for the plan are defined on the basis of deformation rates in the critical area.

In December 2008 the control networks showed a significant increase in the speed of subsidence. This situation led to the activation level of alert in the emergency plan and the meeting of different groups in order to assess the activation of the plan. Finally, the preventive evacuation of about 120 residents from 43 homes in the neighborhood was done.

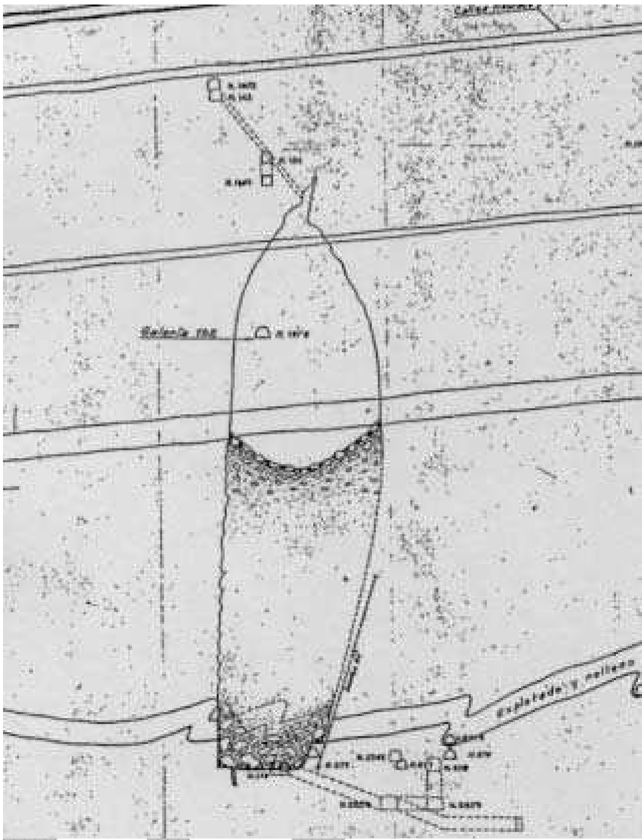

Figura 3.2. Form of cavity according Potasas Ibericas S.A (1954).

3.2 Monitoring network: origin and development

In 1996 Sallent City Council implemented a network leveling in the Estació neighborhood as a result of buildings damages (Batlle Mascareñas 1995). Since 1997 the DPTOP (ICGC) began the necessary work for monitoring movements establishing a high precision topographic leveling network used until today.

In 2000 a first underground monitoring network was implemented, continued to widen over the years. This network is located around the critical area, right above the natural cavity, and is composed of extensometers, inclinometers and piezometers. These instruments are installed at depths that vary between –140 and –15 m, and include 25 rod extensometers, four inclinometers and one piezometer. An automatic measurement system was implemented for collecting data from the extensometers and piezometer (Marturia et al. 2010).

In 2007, at the critical area, 25 precise prisms are installed on the 8 most vulnerable buildings and monitored by an automatic Leica TCA Total Station in order to control the building response.

Monitoring networks in Estació and Rampinya neighborhoods has allowed surveying subsidence and obtaining a huge deformation dataset. This dataset aims to check subsidence speed and define alert triggering levels for emergency plan.

The instrument networks implemented at this moment are:

- High precision topographic leveling. Surface monitoring movements in Estació, Rampinya, Rocaus, Granges i Puigbó neighborhoods.
- Extensometric. Underground monitoring on maximum subsidence sector of Estació neighborhood.
- Tachymetric. Real time building monitoring movements on maximum subsidence sector of Estacio neighborhood.
- Inclinometric. Underground monitoring of horizontal displacements on maximum subsidence sector of Estacio neighborhood.
- Piezometric. Monitoring water level on maximum subsidence sector of Estacio neighborhood.

3.3 Geological context

Sallent town is located in the eastern part of the Tertiary Ebro Basin, known as The Central Catalan Depression (figure 4.1). The basin sediments are composed of erosion products from surrounding Mountains (Pyrenees, Iberian Mountains range and Coastal mountains system) originated during by tectonic processes of the Eocene and Oligocene times. During the Eocene-Oligocene it became an endorheic basin with an open sea cyclic connection. That has allowed the accumulation of large deposits of potassium and sodium salts in the central part of the basin (Cardona formation). These deposits form the so-called Catalan Potassic Basin (IGC, 2009).

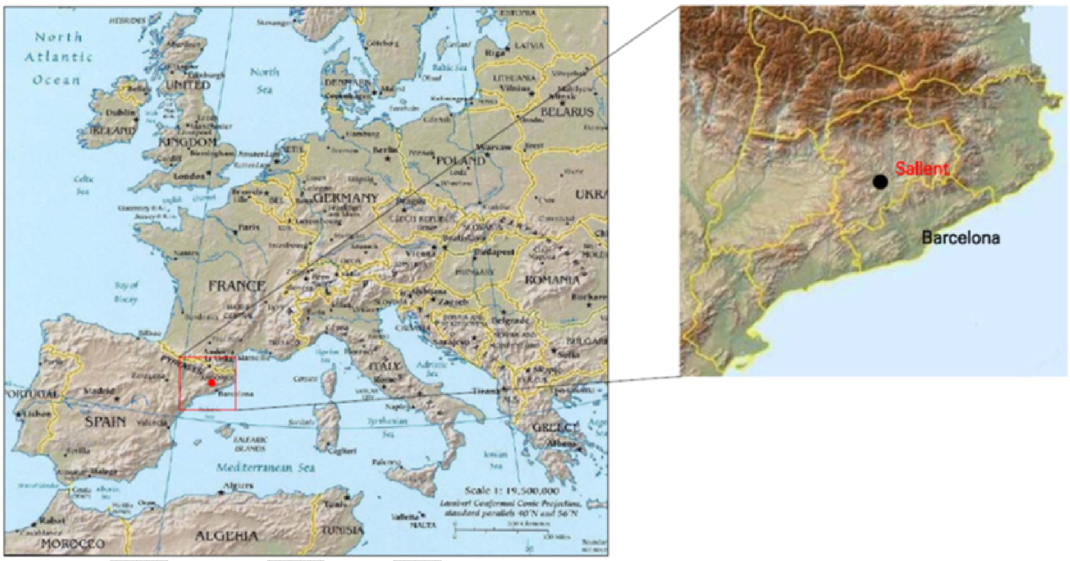

Figura 4.2. Location of Sallent in Catalonia and Europe.

This basin is formed by a thick sedimentary series that includes marine deposits (gypsum and salt), transition evaporitic materials of and thick continental formations. In Sallent surface appear the Oligocene materials from the cover of the salt (figure 4.2). Those materials have been deformed forming large folds resulting from the propagation of the Pyrenean fault.

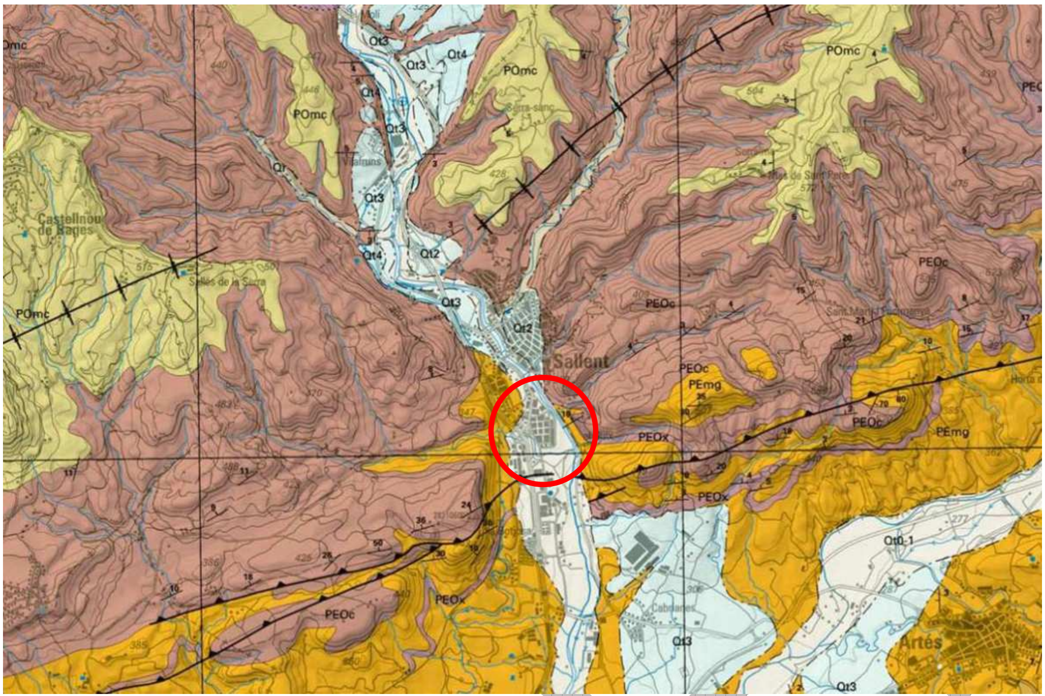

Figure 4.2. Geological map of Sallent zone (extracted from Catalonia Regional Geological Map 1:50000, IGC 2006). ***PEOC*** *micritic limestones,* ***PEmg*** *marls and sandstones,* ***PEOx*** *Gray marl with sandstones and chalks intercalations,* ***POmc*** *Marl with limestone's intercalations.*

3.4 Stratigraphy

The Estació neighborhood subsoil materials consist of a first quaternary fluvial level. Below that are located the Tertiary series, composed mainly by detrital materials with some intercalations of carbonate and evaporitic materials. Those series are the top of the sodium and potassium salts of Cardona formation, as can be seen in detailed stratigraphic column in Figure 4.3 and Figure 4.5.

A detailed description of the stratigraphic series in the Estació neighborhood is described below:

<u>Quaternary alluvial deposits (Qt0-4)</u>. This is the most recent layer in the study area. It is composed by geological materials related with the sedimentary processes of the Llobregat River during the latest Pleistocene and the Holocene. These terrace deposits is composed of clay and silt levels onf the top, and by pebbles and gravels in a sandy and silty matrix on the bottom. This level presents a thickness between 1 and 4 m.

***Artés Formation. Siltstones and sandstones with interbedded limestones and chalks* (PEmg).-** This Eocene formation has a thickness around 140-200m in the Sallent area. The materials comprise consolidated red siltstones levels with sandstone levels (occasionally microconglomerates), which corresponds to unit **Elg**. This series presents limestones and gray marls levels (**Ecc**) up to decametric order (figure 4.5). Red siltstones often contents milimetric to centimetric gypsum nodules. Sandstones levels usually have less than 1 m thick, but may present hectometric to kilometric lateral extension. It should be noted the presence of a 30m thick layer (Guixos de Sallent Formation) constituted by alternating levels of gray siltstones and sandstones that show interspersed centimetric levels of gypsum.

***Cardona Formation.* Evaporitic Deposits (PEs). –** This middle to late Priabonian age formation, comprises a set of evaporitic material with high lateral continuity. Its thickness varies from 300-350m to over 1000m as a result of tectonic processes (Del Santo et al. 2000). Small chemical precipitation cycles (chloride and sulfate salts) are the origin of the evaporitic materials, separated by a thin intercalations of mudstones. These materials are exploited industrially in Sallent, Súria and Cardona. From base to roof is formed by:

- Basal anhydrite, with a 5 to 10m thickness.
- Old Salt or lower halite member, with a 100 to 500 meters o thickness. It is compose by chloride salts, basically sodium salts. The salt has a “dirty” appearance but red colored in the potassium layers.
- Sylvinite. There are three identified levels. The level A of Sylvinite, with a thickness between 2 and 5m. Intermediate Salt between 2 and 3.5 m of thickness. And finally, the level B of Sylvinite with 0.8 m thickness. These thicknesses are referred in Sallent zone and taken from registers of mining boreholes.
- Carnallite. With a thickness of about 60 m, consists of alternating layers of carnallite and salt. This layer is named "Roof Salt”.
- Argillaceous-evaporitic roof member. It has a thickness of about 30m at Sallent zone. It consists of brackish marls with halite crystals; gypsum and very stratified bypiramidal gray quartz, to roof there are limonite and clays intercalations.

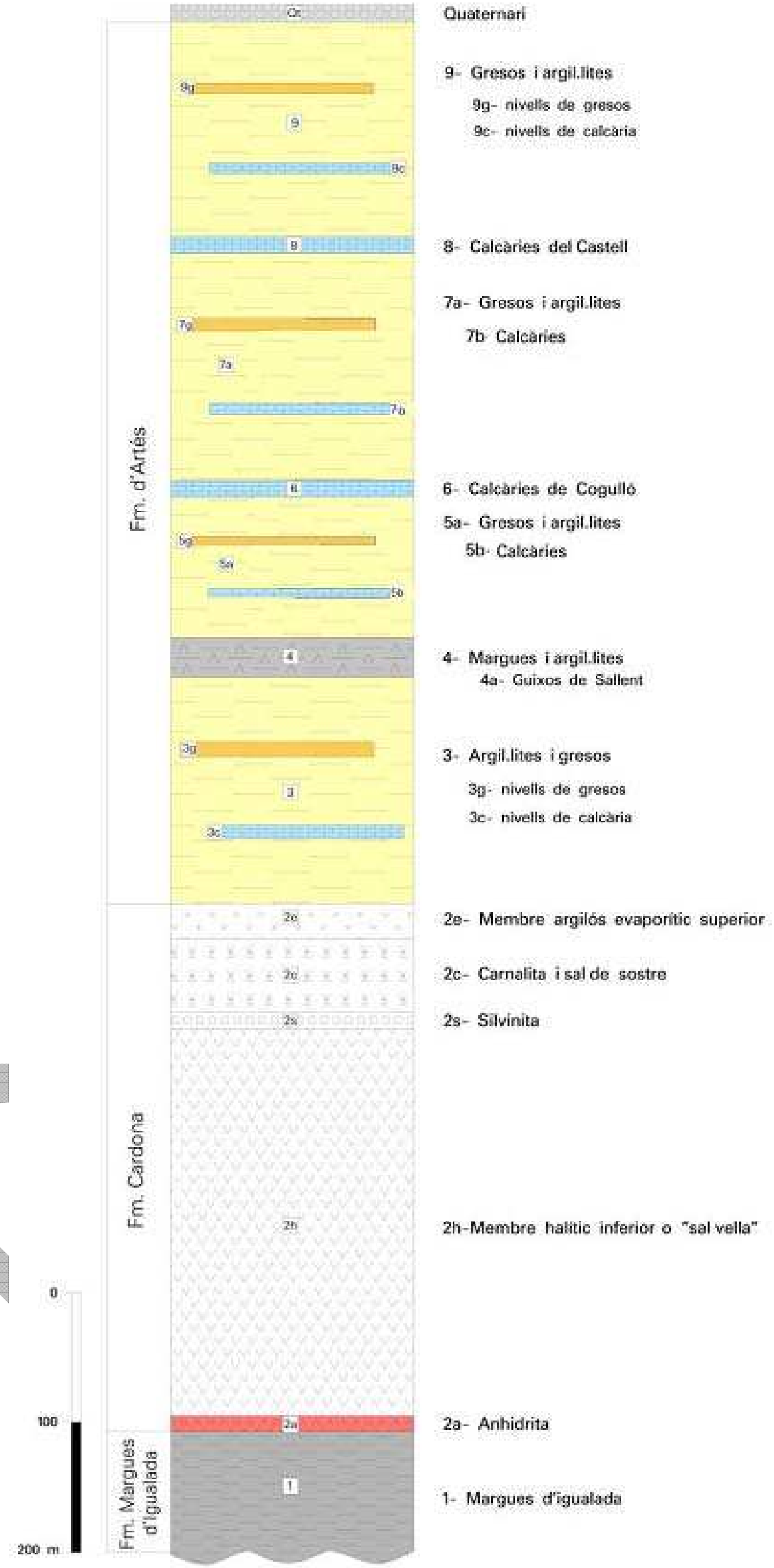

Figura 4.3. Stratigraphic serie of Sallent zone.

3.5 Tectonics

The study area is formed by a monoclinal serie dipping 6º to NNW, forming the Sallent-Callús anticline-syncline. The serie is affected by a thrust fault (Gypsum Fault) of N70ºE direction (SO-NE) that it can be followed along 20km from Cardener River to Santa Maria d'Oló. The fault trace is located in the South of the town (figure 4.4). The Gypsum Fault dip about 20º to the North, but locally it arrives to 40º. Maximum fault scarp takes place in Sallent zone, reaching 70 to 100 m on the vertical. This is detected on the southern edge of the mine.

The thrust fault contains a set of associated a meso-structures including several slip planes, minor faults and some metric and decametric folds in upper and lower block. Some of these minor overlap plans emerge in the proximities of the Estació neighborhood.

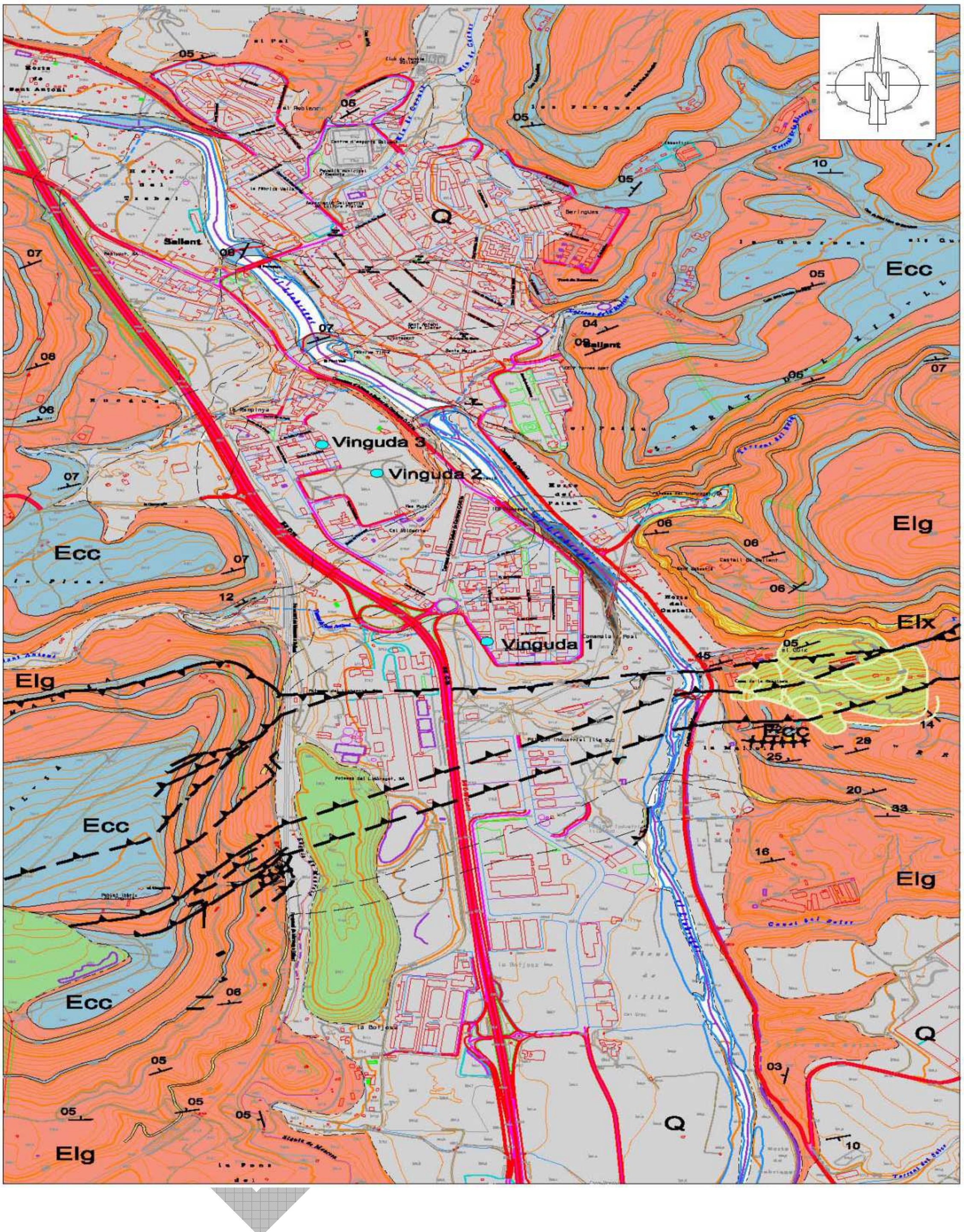

*Figure 4.4. Geological map of Sallent zone at escale 1:10000. **Elg** Siltstones and sandstones, **Ecc** Gray limestones, **Elx** Siltstones and gypsum, **Q** Clays and alluvial gravels.*

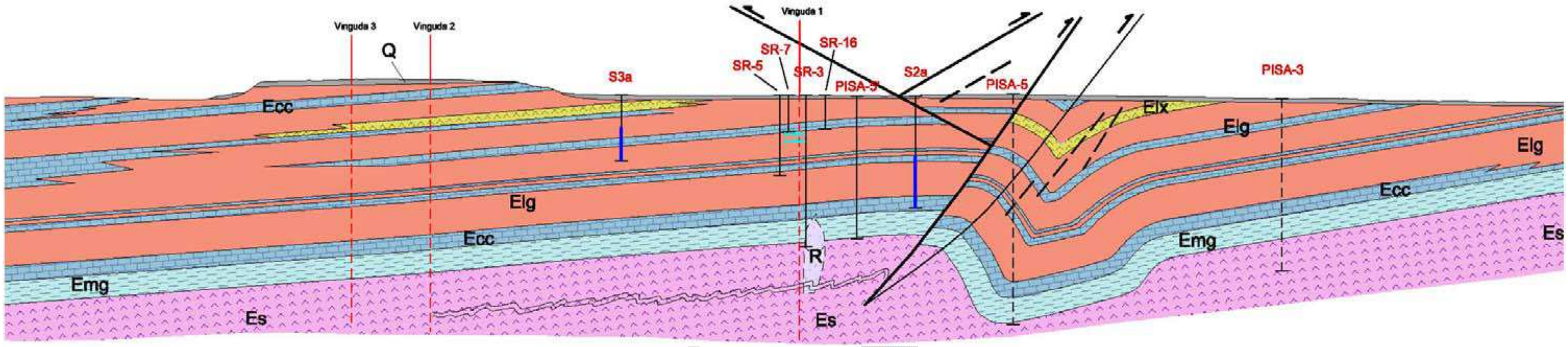

Figure 4.5.Detailed geological longitudinal profile scale 1:10000. ***Es*** *Sodium and Potassium Salts,* ***Emg*** *Grey marls,* ***Elg*** *Siltstones and sandstones,* ***Ecc*** *Gray limestones,* ***Elx*** *Siltstones and gypsum,* ***Q*** *Clays and alluvial gravels,* ***R*** *Dump.*

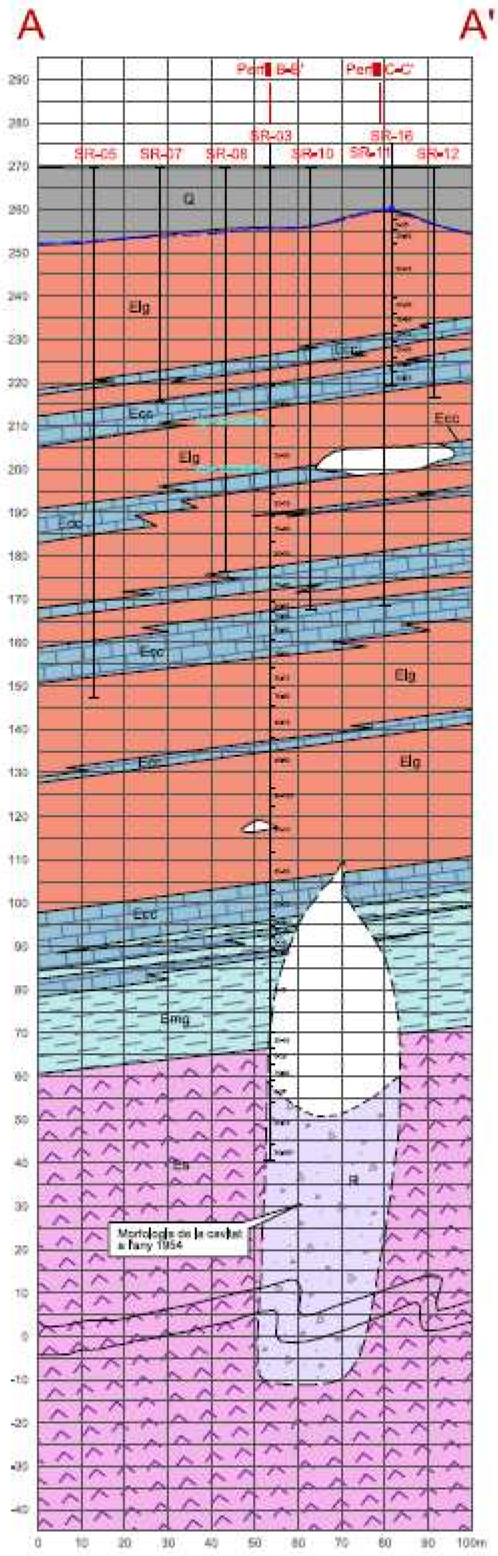

Figura 4.6. Geological-geotechnical profile with geological units and boreholes.

4 Process and causes of subsidence

4.1 Surface movements distribution.

Topographic leveling measurements of subsidence related with the exploitation of the Enrique mine began in 1948 until present (with some gaps). During the operation of the mine the measured subsidence rates was around 7 and 8 cm/year average. Since mine closing the subsidence velocities were reduced to values of 2-3 cm / year.

Between 1997 and mid-2001 velocities remained constants, with a subsidence taxes around 1.5-2.3 cm/year in the maximum subsidence zone. Later on, between on July 2001 the speed movement increases and decreased until February 2004, keeping at the end of this period a velocity rates between 2 and 3.3 cm/year. The distribution of surface movements lay out concentrically around maximum movement area (figure 5.1). In September 2007, new acceleration process occurs reaching values greater than 5 cm/year.

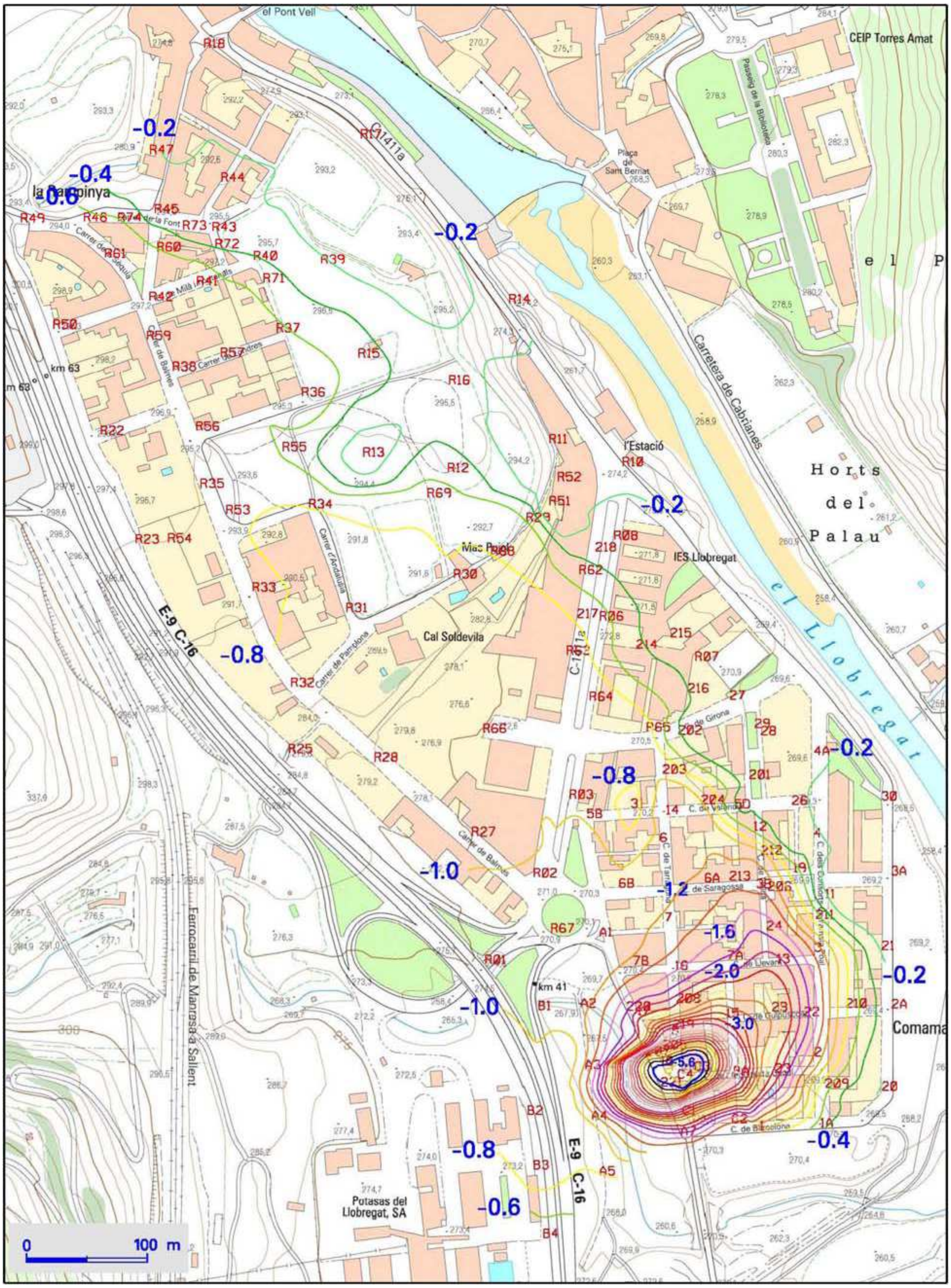

Figure 5.1. Distribution in plant of subsidence velocities measured in 2008. (IGC,2008).

In 2008 there was a strong acceleration of the subsidence velocity (Figure 5.2) which exceeded established thresholds. Between January and April 2009 the subsidence rate was around 9 cm/year, but in May reach to 16cm/any. In 2010 started a deceleration in the subsidence velocity which culminated in September 2010 with the stabilization subsidence velocities around 5.5 and 6.5 cm / year.

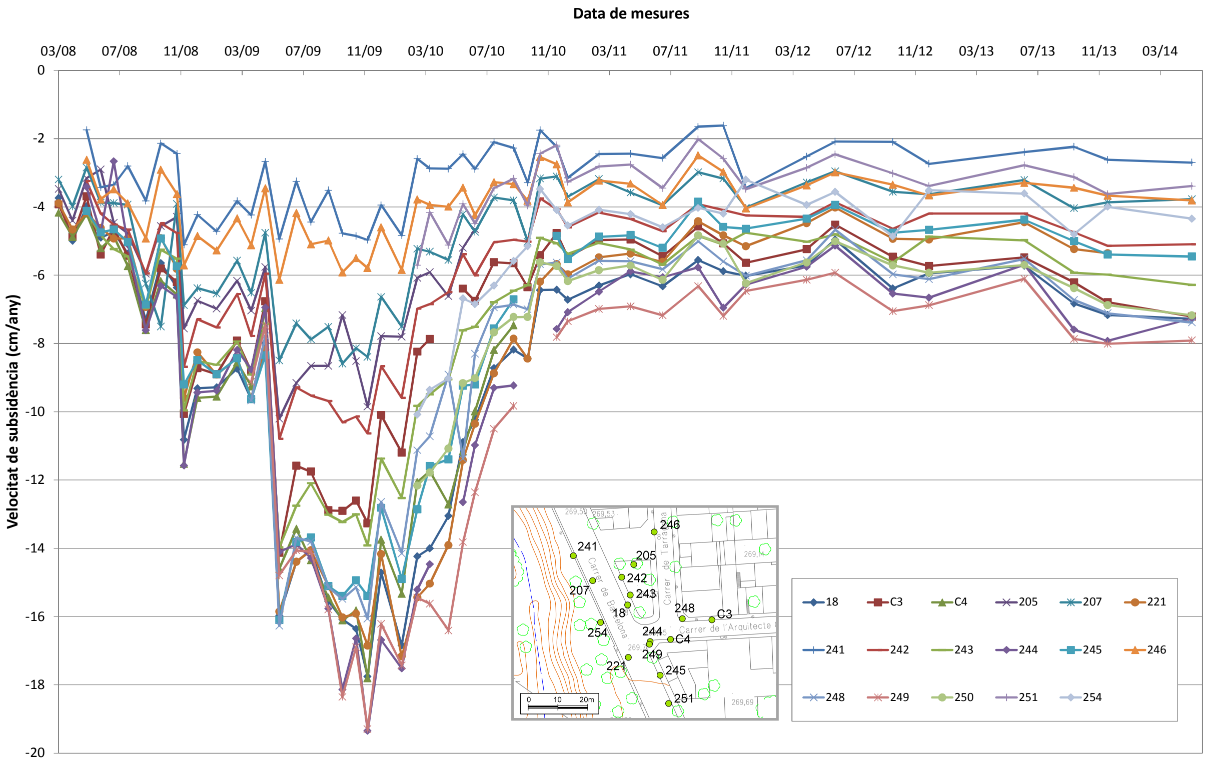

Figure 5.2. Subsidence velocities of the closest points to the area of maximum subsidence, from March 2008 to May 2014.

Since the introduction of the high topographic leveling network in 1997, the sector has recorded a surface subsidence up to 65 cm recorded at control point 18 and C4.

Control Point	Subsidence average speed (cm / year)			Annual subsidence velocity (cm / year)
	December – June	June – September	September – December	
18	-5.72	-6.83	-7.17	-6.30
C3	-3.21	-4.04	-3.87	-3.57
C4	-4.45	-5.24	-5.36	-4.84
207	-2.39	-2.24	-2.62	-2.39
221	-4.20	-4.74	-5.14	-4.53

241	-4.98	-5.93	-5.98	-5.43
242	-5.69	-7.59	-7.93	-6.64
243	-4.38	-5.00	-5.39	-4.74
244	-3.30	-3.44	-3.67	-3.41
245	-5.52	-6.72	-7.11	-6.16
246	-6.11	-7.87	-8.01	-6.95
248	-5.70	-6.38	-6.88	-6.11
249	-2.78	-3.13	-3.62	-3.03
250	-3.61	-4.80	-3.99	-4.01
251	-5.72	-6.83	-7.17	-6.30
254	-3.21	-4.04	-3.87	-3.57

Taula 5.1. Subsidence average speed. Year 2013

4.2 Distribution of subsoil movements

In this section we will focus on describing the subsoil movements with data recorded from the extensometric network located in maximum subsidence area.

4.2.1 Extensometric network

The extensometric network in Estació neighborhood consists of 17 soundings installed with 25 rod extensometers, located at different depths, and 3 incremental extensometers with magnetic rings every meter. In figure 5.3 is showed the position of soundings, while in Table 5.2 indicates the kind of instrumentation installed in each one, their depths and their associated leveling points.

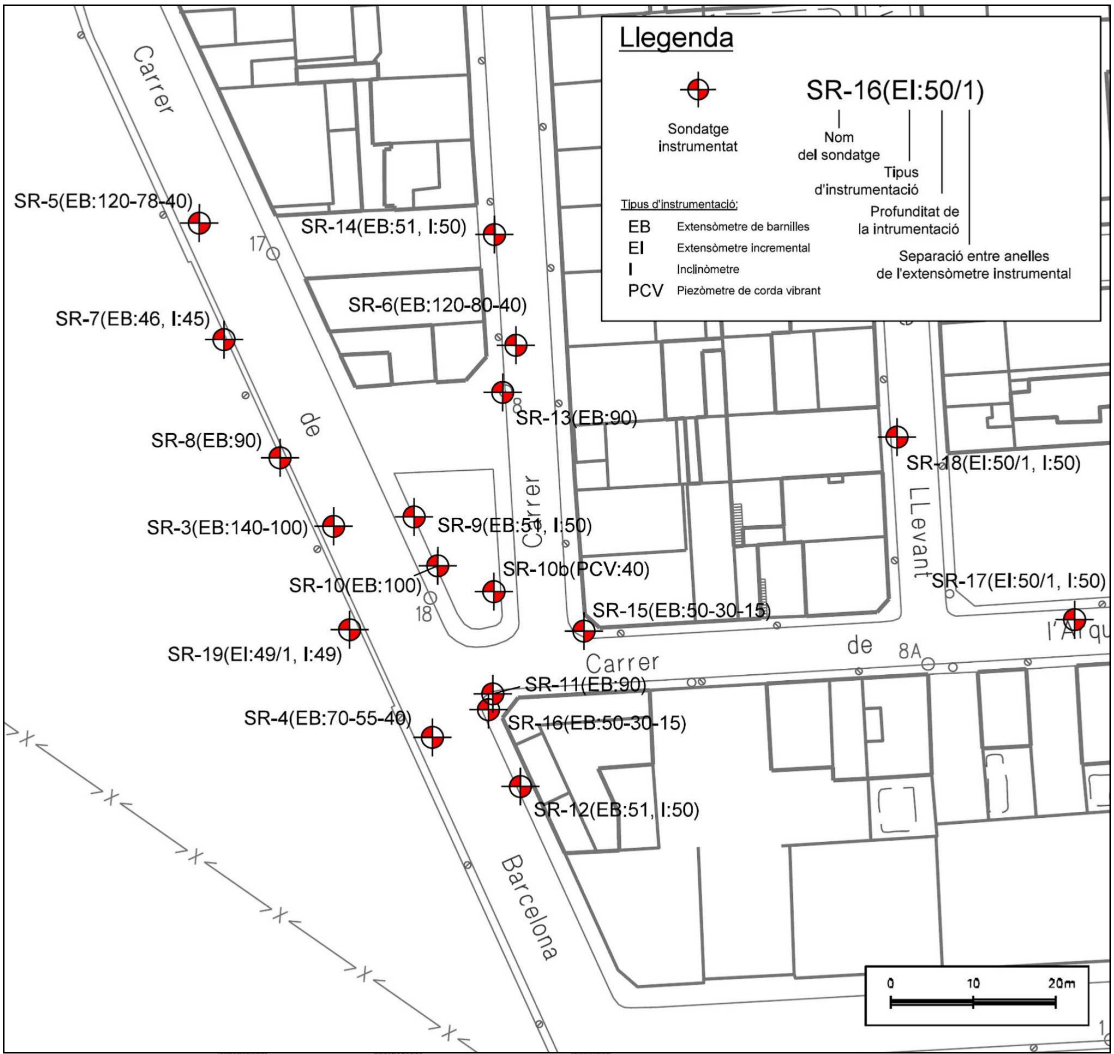

Figure 5.3. Location of extensometric network in Estació neighborhood.

Sounding	Sounding depht. (m)	Leveling Point	Kind of instrumentation	Extensometers depth (m)
SR-3	229	207	2 rod extensometers	140 i 100
SR-4	75	221	2 rod extensometers	70, 55 i 40
SR-5	122	220	3 rod extensometers	120, 78 i 40
SR-6	121	219	3 rod extensometers	120, 80 i 40
SR-7	54	240	inclinometer tube and 1 rod extensometers	46.5
SR-8	93	241	1 rod extensometers	90
SR-9	54	242	inclinometer tube and 1 rod extensometers	50
SR-10	102	243	1 rod extensometers	100
SR-11	101	244	1 rod extensometers	90
SR-12	53	245	inclinometer tube and 1 rod extensometers	50
SR-13	71	246	1 rod extensometers	90

Sounding	Sounding depht. (m)	Leveling Point	Kind of instrumentation	Extensometers depth (m)
SR-14	53	247	inclinometer tube and 1 rod extensometers	50
SR-15	50	248	3 rod extensometers	50, 30 i 15
SR-16	50	249	3 rod extensometers	50, 30 i 15
SR-17	50	-	1 incremental extensometer	Every 1 m
SR-18	50	-	1 incremental extensometer	Every 1 m
SR-19	49	-	1 incremental extensometer	Every 1 m

Taula 5.2. Lists of soundings with instrumentation, depths and associated leveling points.

4.2.2 Subsurface moviment distribution

Data recorded by the extensometric network allow drawing the distribution of subsurface movements.

Establishing the correspondence between leveling points and the extensometric network led to obtain the absolute displacement for each extensometric point. From these data profiles are represented graphically in order to draw displacements detected at different depths (figure 5.4 and 5.5).

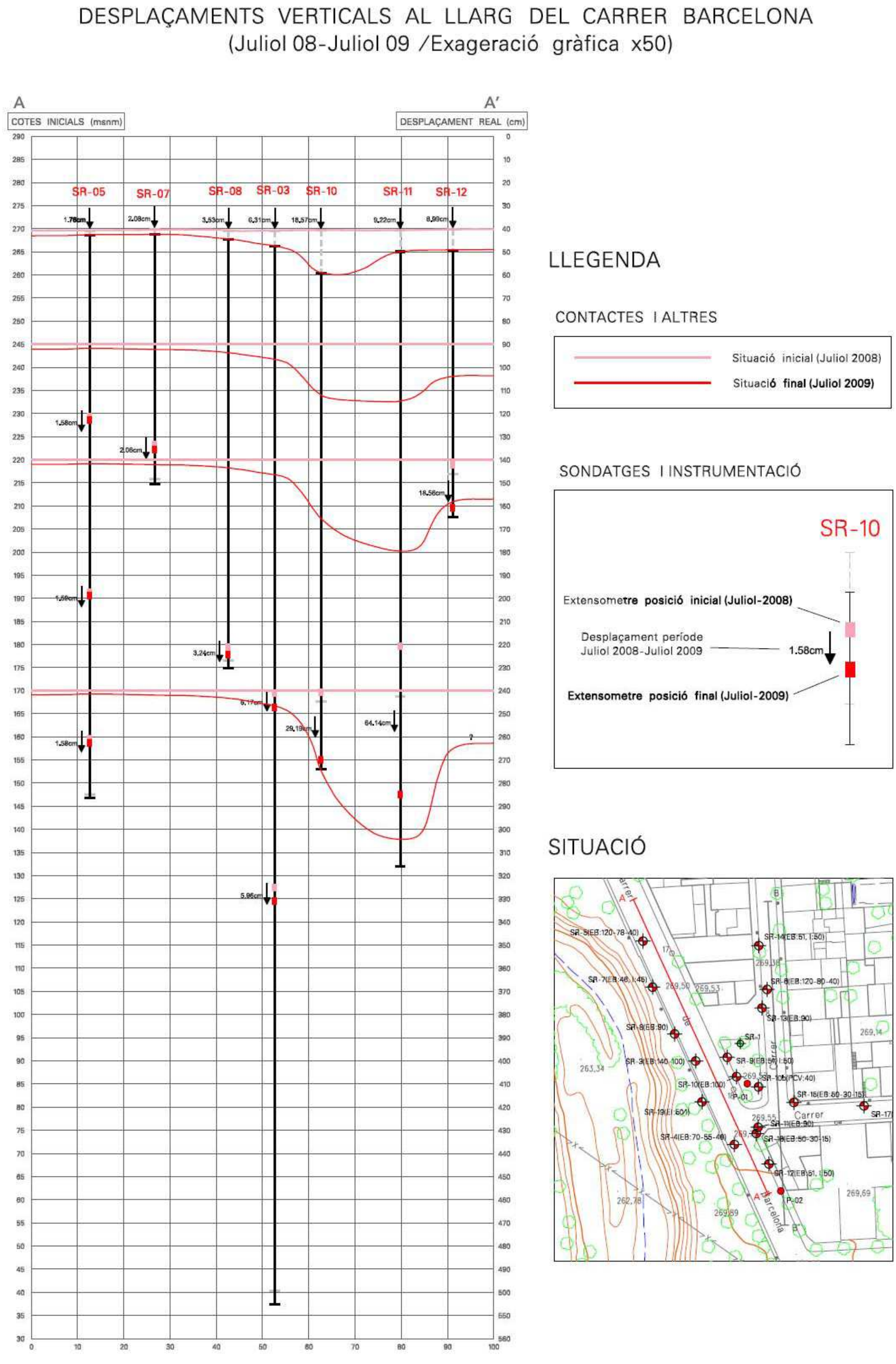

Figure 5.4. Vertical displacements along Barcelona Street (July 2008-July 2009).

The most important displacements take place at points SR-10, SR-11 and SR-12 respectively. From these data is observed that the origin of the displacement is in near point SR-11 at a depth over 100m and attenuated gradually along the NW direction.

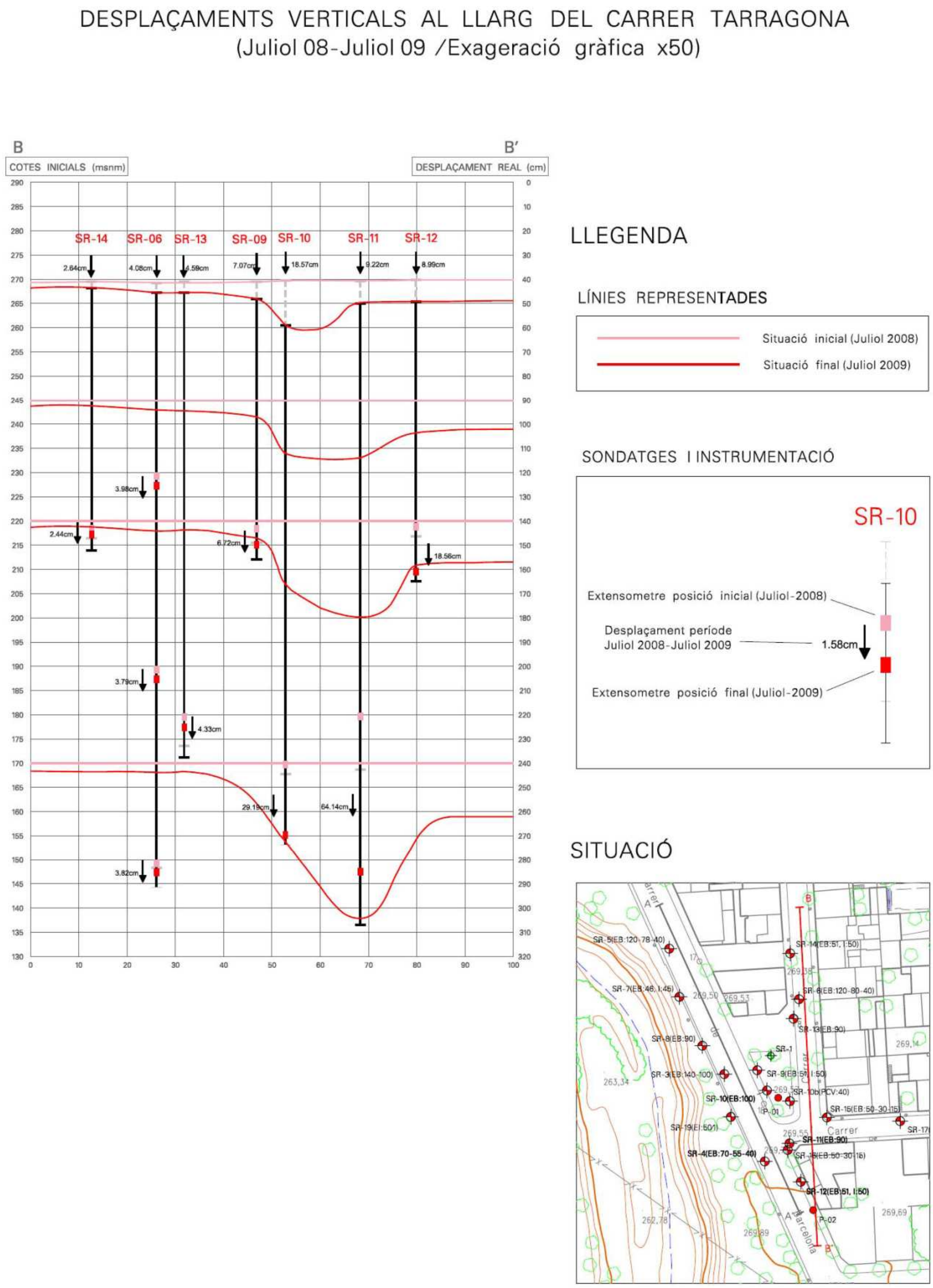

Figure 5.5. Vertical displacements along Tarragona Street (July 2008-July 2009).

4.3 Subsidence origin.

Studies conducted in this area have concluded that generalized subsidence is linked to the exploitation of mine Enrique and the "Big Cavity" located in SW of Estació neighborhood. Both processes are not related to the presence of gypsum karstification. But cannot rule out the effects of some of these karst voids may occasionally affect the generalized subsidence and have some local incidence, especially if voids are located around the surface or in quaternary units.

The geometry of the subsidence locates the highest displacement point on the vertical of the ancient cavern detected in 1954 during the exploitation of the mine, mapped by Potasas Ibéricas S.A (figure 3.2). The distribution of movements in depth obtained from extensometric network is compatible with the presence of cavity in depth.

The existence of the cave can be related with water circulation from deep aquifers to the shallow alluvial aquifer through the geological structures in the area, because the piezometric level of deep Tertiary aquifer is close to topographic surface.

4.4 Propagation mechanism of deformation.

It has been observed that the displacements increase in depth as the distance to the hypothetical cavity decreases. In Sallent the tertiary geological cover is mainly formed by slightly deformable rocks with fragile behavior. For this reason the rocks deformation is transmitted upward through a system of subvertical fractures. This mechanism of displacement can lead abrupt movements or even the sudden collapse of the ground.

The phenomenon evolution is given by the vertical propagation of stress. The greatest stress is generated in the roof of the cavity causing its progressive detachment. This provokes upward evolution of the void preserving initial diameter.

This model has been proposed by Terzaghi in Windsor case (Nieto and Russell, 1984), where the initial cavity was developed close to 400m depth and was progressing through cover up to generate a surface depression. This case is quite similar to Sallent geological characteristics. The evolution of the void through cover was estimated strictly vertical, and increasing the diameter of the void would occur in Cardona Formation by dissolution of the salt.

5 Current situation of Estació neighborhood.

5.1 Activation of the emergency plan, in warning level, at Estacio neighborhood.

On 23 December 2008, an acceleration of subsoil movements provokes the activation of the emergency plan by the Catalan Civil Protection. This implied the preventive and scheduled evacuation in January 2009 of the neighbors located in the area with a higher risk of collapse: around 120 residents of 43 homes. . A result of this was implemented a compensation plan that implied the evacuation of whole neighborhood residents and the demolition of 405 properties.

In 2014 has been started the eighth stage of demolition, including 16 of the 35 properties that remain in the Estació neighborhood. In 2015 remaining buildings will be demolished.

Figure 6.1Situation of Estació neighborhood without edifications in ground zero (February 2014).

5.2 Instrumentation affectation

The evacuation and buildings demolition of in the neighborhood has consequences at instrumentation network. The main affection has been in the automatic tachymetric system because prisms were located in buildings front. This means that an alternative support must be found for most of these prisms. We have identified some old streetlight (Figure 6.2.) that can serve as a basis, once properly equipped. But to keep the information density for ground zero is thought installing of a series of concrete pillars conveniently located to allow monitor in an effective way the area of maximum collapse.

Figure 6.2 .Possible basis for the location of prisms and WI-GIM sensors.

The other monitoring networks have had small affectations by the buildings demolition. Other problems became from vandalism act because the abandonment of the district but monitoring systems continue working properly.

6 Recommendations for WI-GIM implementation

Subsidence in Sallent Estacio district is well monitored and complies with the requirements for the implementation of Wi-GIM system:

1. Is an active movement.
2. Its associated to a high risk.
3. The speed is high enough for the Wi-GIM system in order to appreciate the displacements.
4. The velocity is quite constant.
5. It is easily accessible, in order to facilitate frequent instrumentation checks, and ensure safety conditions to operators.
6. It is in an urbanized area and near to communication routes (although this is also the main handicap of the site, where some sensors have been stolen recently; for this reason, Wi-GIM sensors will have to be hidden as much as possible).
7. Its surface is small enough to be fully covered by sensors.
8. It is observable from some panoramic points, which are necessary for the implementation of the traditional monitoring as well as the Wi-GIM Systems.
9. The investigated area has a good GSM cover for remote monitoring data transmission.

The mass movement magnitude, distribution, kinematics and geological setting are well known. All this knowledge acquired has to be processed and analyzed to properly design the overall wireless sensor network and to derive the specifications for both the sensors and the base station devices designing.

Information from different monitoring networks has put in evidence that the movement still active, probably due to the rise of the cavity to the surface.

The subsidence are distributed throughout the area occupied by mine Enrique with average speeds of 1 to 2 cm/year, except for specific sector of the Estació neighborhood where current speeds are above 6/7 cm/year. In this sector, subsidence velocity measurements have a concentric distribution; the maximum collapse could be defined as a focal point, generated by karstification of saline formation (Cardona Formation).

Consequently the installations of the WI-GIM system should be cover the extension of the Estació neighborhood, but must be focused on subsidence occur with higher speeds.

To ensure and facilitate the reliability, robustness and maintenance of the WI-GIM system, is recommended that WI-GIM sensors be installed sharing location, infrastructure and supplies with TCA network. This will allow the measures obtained for this network will be supported by the measurements obtained for the other auscultation networks of the neighborhood

7 References.

- Batlle, A., Mascareñas, P. (1995). Diagnosi geotècnica inicial referent a l'aparició de lesions generalitzades en alguns edificis del sector de l'Estació, a Sallent. Batlle & Mascareñas.
- Del Valle, J. (1997). Situación teòrica actual de la mina Enrique.
- Díaz, J. i Jodar, M., 1996. Caracterización hidrogeológica del sector Callús-Santpedor-Sallent (Barcelona). 30 CIHS. Barcelona. Document inèdit.
- Escorcia, J., Rosario, F., Marsili, G. 2009. Estudio hidrogeológico de los acuíferos terciarios y cuaternarios del sector de Sallent, Balsareny, Santpedor, Súria y Callús, Barcelona. 43 CIHS Barcelona.
- ICC (2003). Estudi del procés d'esfondrament del terreny que afecta els barris de l'Estació i de la Rampinya de Sallent (Bages) 1997 – 2003. ICC/AR-151-03.
- IGC (2006). Mapa geològic comarcal de Catalunya 1:50.000. Full 7, Bages.
- IGC (2006). Auscultació i anàlisis del procés d'esfondrament del terreny que afecta els barris de l'Estació i la Rampinya de Sallent.
- IGC (2008). Auscultació dels barris de l'Estació i de la Rampinya. (Sallent, Bages). Resum 2008. Informe IGC AP-202/08.
- IGC (2009). Recopilació, anàlisis i síntesis de la informació geològica sobre el procés de subsidència a Sallent (2005-2009). IGC/AP-134-09.
- López, F. (2008). Avaluació de la subsidència i risc d'esfondrament al barri de l'Estació de Sallent. GEOCAT-IGC.
- Martínez, P., Piña, J., Ribera, F., Dorca, H., Soler, A., Otero, N., Palau, J., Puig, R. (2009). Estudi hidrogeològic de l'entorn de Sallent i Balsareny (Conca Potàssica Catalana). FICHS.

- Marturia, J., Ripoll, J., Concha, A., Barbera, M. (2010). Monitoring techniques for analysing subsidence: a basis for implementing an Early Warning System. In proceeding of: VIII International Symposium on Land Subsidence, At Querétaro, México, Volume: Land Subsidence, Associated Hazards and the Role of Natural Resources Development Carreon-Freyre, D., M. Cerca, D.L. Galloway (Eds). IAHS Publication 339

- Moya, J., Moncada, G., Ramos, S., Matallana, M., (1979). Relleno de la mina de sales potásicas "Enrique" en Cataluña propiedad de Unión Explosivos Rio Tinto. 10º Congreso Mundial de Mineria.
- Nieto, A.S. i Russel, D.G, 1984. Sinkhole developement in windsor-Detroit solution mines and the role of downward mass transfer in subsidence. In Situ: Oil-Coal-Shale-Minerals, v 8, n 3, pp. 293.

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