

## Anthropostratigraphy: New lithological units of the Quaternary controlled by human activity

### Antropoestratigrafía: nuevas unidades litológicas del Cuaternario controladas por la actividad humana

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#### Abstract

Many areas around the world such as the Mediterranean region have been inhabited without interruption for thousands of years. This is the case of the city of Barcelona (Spain), where remains of human settlements dating from pre-Roman times until the present have been found. A detailed geological mapping of the area occupied by the city of Barcelona raises a number of questions about the Holocene stratigraphy affected by human activity. In the old urban and surrounding areas most of the sedimentary deposits accumulated during settlement result from human interactions. Thus, new anthropostratigraphic units are proposed. The sedimentary deposits and the infill of rock excavations due to human presence may be divided into three categories: *Natural lithoanthropogenic units (NAU)* when their formation is not directly affected by anthropogenic activity but these contain artefacts of human origin. *Induced lithoanthropogenic units (IAU)* when natural processes together with human actions produce sedimentation or erosion due to natural phenomena; *Constructed lithoanthropogenic units (CAU)* when sedimentary accumulations and sharp contacts result from direct human activity.

*Keywords:* Urban geology, Quaternary stratigraphy, geoarchaeology, lithoanthropogenic units, Barcelona, NE Spain.

#### Resumen

A lo largo de todo el globo terrestre, existen muchas zonas como la región mediterránea que han sido habitadas ininterrumpidamente durante miles de años. Este es el caso de la ciudad de Barcelona donde se han encontrado restos de asentamientos humanos desde los tiempos pre-romanos hasta la actualidad. Un mapa geológico detallado de la zona ocupada por la ciudad de Barcelona plantea una serie de interrogantes sobre la estratigrafía del Holoceno influenciado por la actividad humana. En la zona urbana antigua y en áreas circundantes, la mayoría de los depósitos acumulados durante el asentamiento se han producido por las interacciones humanas. Por tanto, se proponen nuevas unidades antropoestratigráficas. Los depósitos sedimentarios así como los rellenos de las

excavaciones debidos a la presencia humana pueden ser divididos en tres categorías: *Unidades litoantropogénicas naturales (NAU)* cuando su generación no ha sido afectada directamente por la actividad humana, pero contienen diversos artefactos artificiales. *Unidades litoantropogénicas inducidas (IAU)* cuando los procesos naturales junto a las acciones humanas producen sedimentación o erosión debido a los fenómenos naturales. *Unidades litoantropogénicas construidas (CAU)* cuando las acumulaciones sedimentarias y los contactos nítidos son el resultado de la actividad humana directa.

*Palabras clave:* Geología urbana, estratigrafía del Cuaternario, unidades litoantropogénicas, geoarqueología, Barcelona, NE de España.

## 1. Introduction

A recent geological mapping of the area occupied by the city of Barcelona (Fig. 1) raises a number of questions about the Holocene stratigraphy (Head et al., 2008) affected by human activity (Cirés et al., 2009; Riba and Colombo, 2009).

There are few data on the detailed geology of urban habitats that have undergone repeated modifications during human settlement. The survey undertaken in the urban area of Barcelona enabled us to determine the main methods of study, outline the major geological problems, and define the specific stratigraphic units.

Sedimentary rock bodies accumulated during human settlement may be modified by anthropogenic activities (Kirwan et al., 2011, Kirwan and Murray, 2012). A number of areas such as the Mediterranean region have been inhabited without interruption for thousands of years. This is the case of Barcelona (Fig. 2), where remnants dating from pre-Roman times until the present have been found. These artefacts are usually mixed with natural sedimentary materials resulting from the geological sedimentary processes in urbanised areas.

The interaction between human activity and geology (Crutzen, 2002) in urbanised areas gives rise to the formation of diverse sedimentary lithosomes. These rock bodies must be characterized and arranged in stratigraphic units to enable us to reconstruct the geological and human history of these areas. It should be borne in mind that natural forces and human influences (Hooke, 2000; Syvitski et al., 2005; Wilkinson, 2005) can be either depositional or erosional.

This work constitutes a new stratigraphic approach to the study of human-induced sedimentary accumulations. Thus, in the upper Holocene, new units may be distinguished in urbanised areas: the *anthropogenic stratigraphic units*.

## 2. Quaternary chronostratigraphic units

In a very brief chapter, the 9 G, The International Stratigraphic Guide (ISG) states that “The basic principles used in subdividing the Quaternary into chronostratigraphic units are the same as for other Phanerozoic

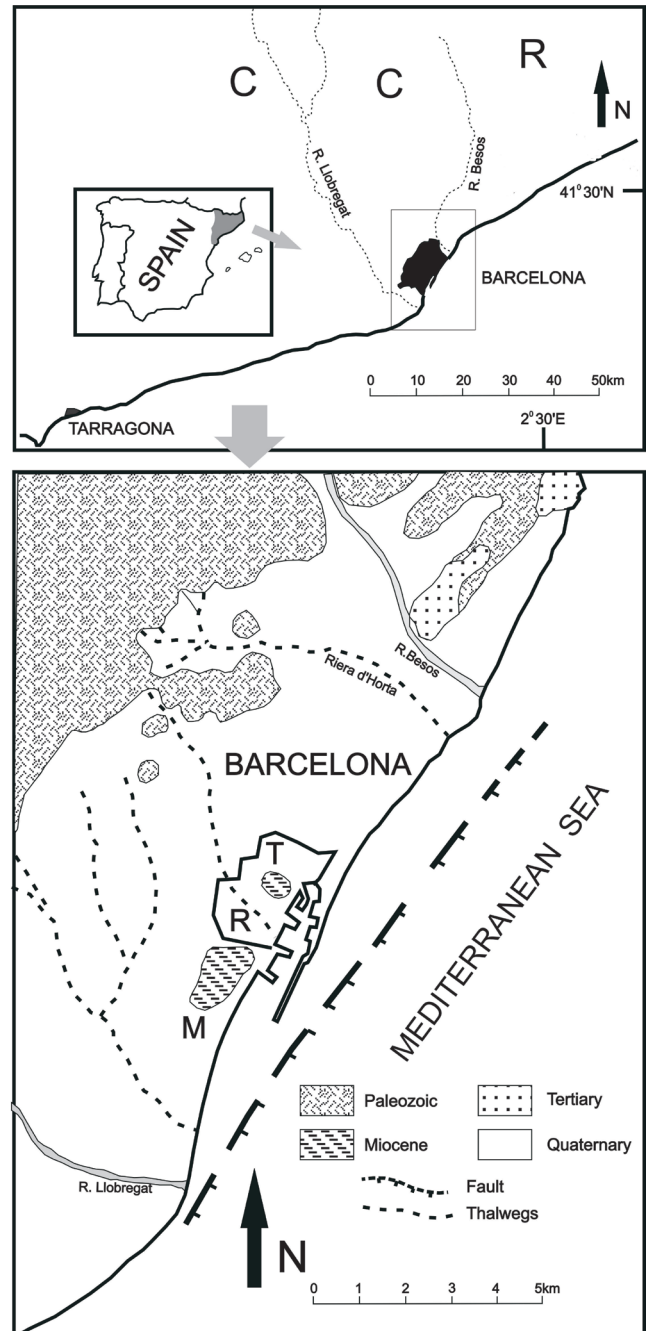


Fig. 1.- Situation of the study area and location of the city of Barcelona. The Ciutat Vella (Old City) quarter is indicated. CCR, Catalan Coastal Ranges; T, Taber; M, Montjuïc; R, The Ramblas.

Fig. 1.- Situación de la zona de estudio y localización de la ciudad de Barcelona. Se indica el distrito de Ciutat Vella (Ciudad Antigua). CCR, Cadenas Costeras Catalanas; T, Taber; M, Montjuïc; R, Las Ramblas.

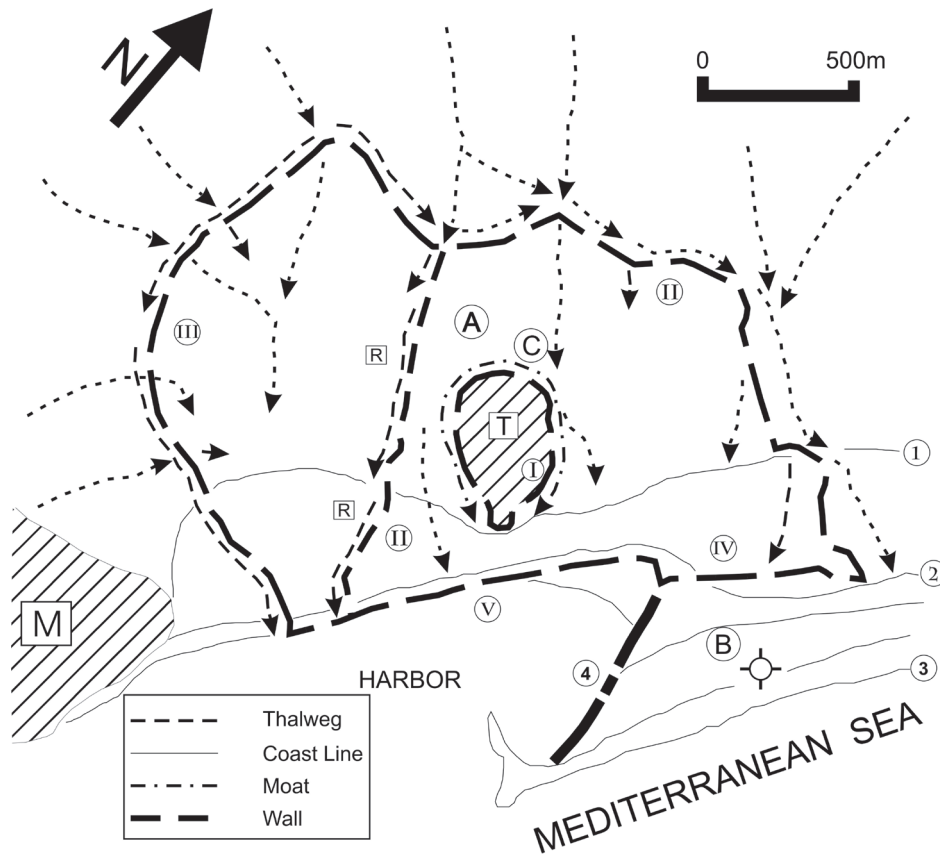


Fig. 2.- Sketch of the Ciutat Vella quarter, where the walls are displayed: I, I Century BC and III Century AD. The following chronology refers to AD: II, XIII Century; III, XIV Century; IV, XV Century; V, XVI Century. Coast lines; 1, X Century; 2, XV Century; 3, XVIII Century. A, Villa de Madrid Square; B, Barceloneta Quarter; C, Cathedral Avenue. Miocene outcrops: T, Taber; M, Montjuic. 4, East Pier of the Barcelona Harbour, built between XV and XVIII Centuries.

Fig. 2.- Esquema del distrito de Ciutat Vella, donde se aprecian las murallas: I, Siglo I BC y Siglo III AD. La cronología siguiente queda referida en AD: II, Siglo XIII; III, Siglo XIV; IV, Siglo XV; V, Siglo XVI. Líneas de costa; 1, Siglo X; 2, Siglo XV; 3, Siglo XVIII. A, Plaza de la Villa de Madrid; B, Distrito de la Barceloneta; C, Avenida de la Catedral. Aflojamientos del Mioceno: T, Taber; M, Montjuic. 4, Muelle del Este del Puerto de Barcelona, construido entre los siglos XV y XVIII.

chronostratigraphic units, although the methods of time correlation may have a different emphasis. As in the case of other chronostratigraphic units, those of the Quaternary require boundary definitions and designation of boundary stratotypes” (Murphy and Salvador, 1999).

Given the large number of geological studies of the most recent period of the Earth affected by human presence, a multidisciplinary stratigraphic approach should be adopted to improve our understanding of Quaternary stratigraphy.

The Quaternary has been characterized by a series of ice ages interrupted by interglacial periods in middle-high latitudes of the Northern Hemisphere. It therefore seems reasonable that the geographical regions most affected by glacial deposits are those areas where the studies of Quaternary stratigraphy are more detailed and more frequent (Mangerud et al., 1974; Gibbard et al., 2005).

The issue of the Lithuanian Stratigraphic Guide (LSG) provides a general approach (Grigelis, 2002) that makes up for the scant reference to the Quaternary made by the International Stratigraphic Guide (ISG). New stratigraphic terms have been introduced into the LSG, where the Quaternary stratigraphic subdivision is established by applying a climatostratigraphic criterion. As a result, the climatostratigraphic units correspond to chronostratigraphic ones in the case of the Quaternary. Thus, the climatostratigraphic units are equivalent to the geochrono-

logical ones (Head et al., 2008).

In settlements older than 2000 years the lithostratigraphy provides evidence (artefacts) in differentiated units that are equivalent to chronostratigraphic ones. In other urbanised areas of Catalonia (NE, Spain) such as the city of Reus, similar artefacts have been found (Mir and Salas, 1979).

### 3. Holocene and Late Pleistocene stratigraphy

Despite its interest (Grigelis, 2002), the study of the Late Pleistocene (Head et al., 2008) and the Holocene (Gradstein 2006) poses a number of questions (Voisin, 2010; Walsh, 2006). Within a very short time span, the identification of small geological events separated by a few hundred or a few thousand years (Italian Commission on Stratigraphy, 2002) enables us to obtain accurate results. Correlation is not easy despite the existence of the many methods of study.

In some cases lacustrine (Copons and Bordonau, 1996), loess (Muhs et al., 1999), marine (Cacho et al., 2001) and ice-cores (Björck et al., 1998) present continuous successions that enable us to follow the classic stratigraphic methods. Sedimentary deposits usually occur in isolated outcrops and can be dated in accordance with the standard stratigraphic Quaternary scale, using radiometric, palaeontological and archaeological methods.

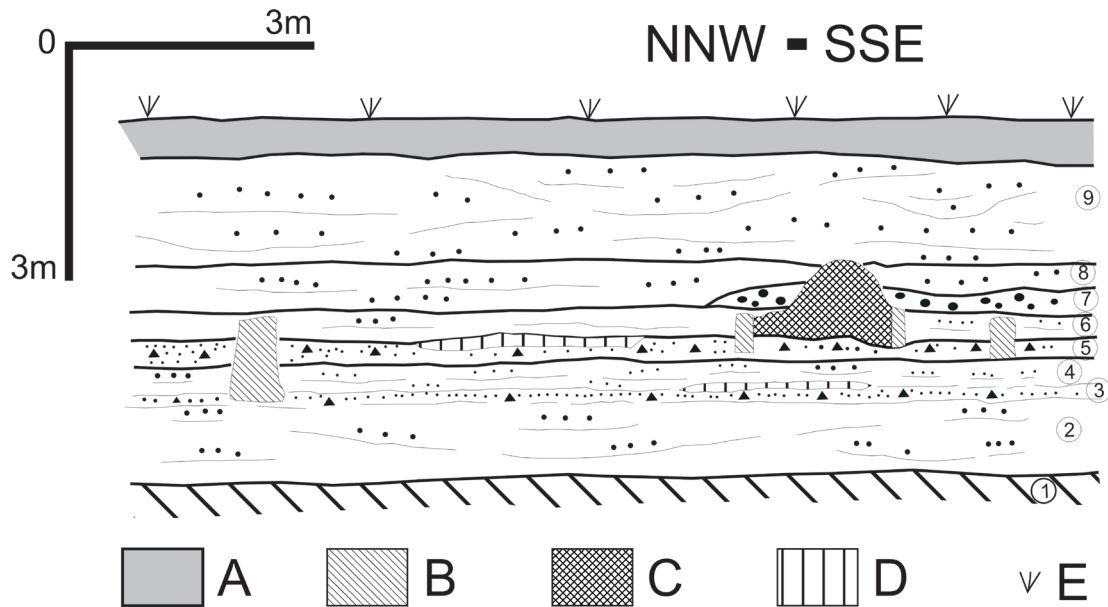


Fig. 3.- The western sector of the archaeological open pit section at the Villa de Madrid square displays the superposition of two (units 8 and 9) *natural lithoanthropogenic units* derived from the Riera d'en Malla (The Ramblas) by natural processes. 1, Early Quaternary basement; 2, Sandy materials with fragments of Iberian ceramics; 3, Roman Road base; 4, Sandy materials with fragments of Roman ceramics; 5, Flattened base of Roman road; 6, Sandy materials with fragments of Roman ceramics; 7, Locally-derived debris flow deposits; 8, Sandy materials with fragments of Roman (III Century) ceramics; 9, Sandy materials with fragments of Iberian and Roman (I Century) ceramics. Units 8 and 9 are younger than III Century and precede the construction of the medieval walls (XIII Century). A, recent debris (XVIII-XX Centuries); B, Roman ruins; C, Roman graves; D, Roman road paving; E, Level of present square.

Fig. 3.- El sector occidental de la excavación arqueológica de la Plaza de la Villa de Madrid muestra la superposición de dos (8 y 9) *unidades lithoanthropogenicas naturales* derivadas de la Riera d'en Malla (Las Ramblas) mediante procesos naturales. 1, Basamento del Cuaternario inferior; 2, Materiales arenosos con fragmentos de cerámica ibera; 3, Base de la calzada romana; 4, Materiales arenosos con fragmentos de cerámica romana; 5, Explanación basal de la calzada romana; 6, Materiales arenosos con fragmentos de cerámica romana; 7, Depósitos de flujos de detritos de origen local; 8, Materiales arenosos con fragmentos de cerámica romana (Siglo III); 9, Materiales arenosos con fragmentos de cerámica romana (Siglo I). Las unidades 8 y 9 son posteriores al siglo III y anteriores a la construcción de la muralla medieval (Siglo XIII). A, detritos recientes (Siglos XVIII-XX); B, Ruinas romanas; C, Tumbas romanas; D, Pavimento de la calzada romana; E, nivel de la plaza actual.

In recent years, attention has been increasingly focused on defining and correlating the human-influenced sedimentary accumulations. Archaeological studies (Butzer, 1980) have resulted in the use of prehistoric time scales despite the fact that little attention has been paid to the dating of the Late Quaternary history related to the role of human presence in urbanised areas. Our aim is to promote the use of the new lithoanthropogenic units in geoarchaeological studies and procedures (Rapp and Hill, 1998; Ghilardi and Desruelles, 2009; Zalasiewicz, 2008, 2010; Zalasiewicz, et al., 2008; Williams et al., 2011).

#### 4. Anthropogenic stratigraphic units

As a result of the continuous settlement of humans in a given area, geological products have been affected by anthropogenic action in many situations. We seek to clarify the interactions among human activities and the coeval sedimentary environments. Many sedimentary bodies and all mechanical modifications of the rocks result from

human activity. A new category of stratigraphic units is proposed: *anthropogenic stratigraphic units*.

These units are usually composed of sedimentary rock bodies with clear morphological boundaries. Thus, they are of limited extension because they infill voids and depressions. These depressions were produced by earlier settlements with the result that their infills, characterized by different lithologies, correspond to *lithoanthropogenic stratigraphic units*.

Human-influenced sedimentary bodies and rock mechanical modifications may be divided into three categories:

*Natural lithoanthropogenic units (NAU)*. These units contain materials and artefacts of human origin although their formation is usually not directly caused by anthropogenic activity e.g. prehistoric axes, ceramic fragments ...etc. found in sedimentary horizons or in alluvial terraces. In this case, human remains and artefacts act as clasts (Fig. 3).

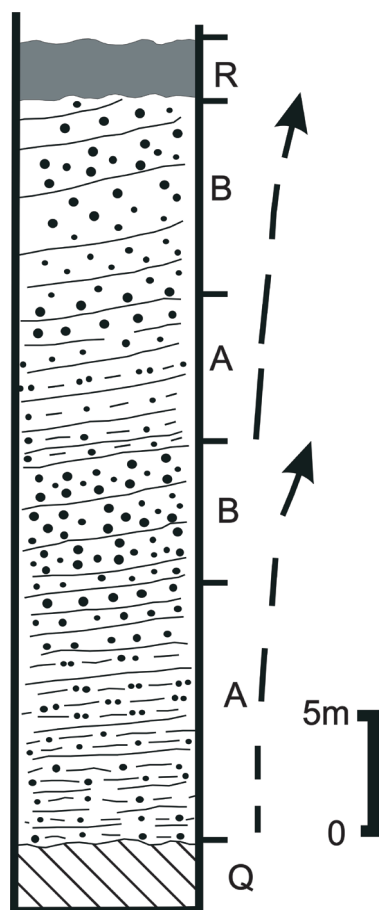


Fig. 4.- The log of the Barceloneta (Gasómetro) borehole shows the vertical distribution of materials accumulated by the action of the sandy longshore current from the NE towards the SW obstructed by the East Pier of the Barcelona Harbour. The sandy accumulations are indicated by arrows. The sandy accumulations are *induced lithoanthropogenic units*. Q, Late Quaternary materials; A, Fine-grained sands; B, Coarse-grained sands; R, recent debris (XIX-XX Centuries).

Fig. 4.- El perfil estratigráfico del sondeo de la Barceloneta (Gasómetro) muestra la distribución vertical de los materiales acumulados por la corriente arenosa de deriva, procedente del NE hacia el SO, obstruida por el dique del Este del Puerto de Barcelona. Las flechas indican dos secuencias de progradación de playa. Las acumulaciones arenosas corresponden a *unidades litoantropogénicas inducidas*. Q, Materiales del Cuaternario superior; A, Arenas de granulometría fina; B, Arenas de granulometría gruesa; R, Detritus recientes (Siglos XIX-XX).

*Induced lithoanthropogenic units (IAU)*. Sedimentation or erosion is produced by a combination of natural processes and human activity, e.g. the construction of a dam has a considerable influence on the geological behaviour of the river (Fig. 4).

*Constructed lithoanthropogenic units (CAU)*. These correspond to sedimentary bodies that result from the direct influence of human activity (Fig. 5), e.g. accumulation of mine rejects and urban waste, infilled quarries, etc.

These three units are often present in urbanised areas where the IAUs are of particular interest since they play a major role in the history and development of the town.

The Barceloneta district, for example, which is adjacent to the harbour, came into existence some centuries ago as a result of the interaction of longshore sandy currents and an artificial pier. Two sequences of beach progradation (Carsí, 1949) are interpreted as IAUs.

Other examples that offer new insights into some aspects of the history of Barcelona include the overflow of the Ramblas (Riera d'en Malla – intermittent stream) towards the low-lying areas of the Ciutat Vella district (Duran, 1963), which results in different levels of NAUs, and the infill of the moat of the Roman walls (Blasco et al., 1992), which gives rise to a CAU.

## 5. Geological mapping of urbanised areas

The geological maps of urbanised areas are the result of a study of the outcrops that are randomly distributed in the city area. However, a tentative correlation between well-known sites can be made despite the considerable difficulty of mapping extensive built-up areas,

Collaboration between geologists, historians and archaeologists is of paramount importance (Solé Sabarís, 1963). Thus, sedimentation analysis is the responsibility of geologists, whereas historians and archaeologists are concerned with establishing the age and origin of human remains and artefacts. Accordingly, human-made clasts found in Late Quaternary (Head et al., 2008) stratigraphic successions allow us to create *anthropozones* similar to geological biozones in older stratigraphic successions. Thus, these can only be applied to the accumulations in which there is a demonstrable human influence. A detailed knowledge of the history of a specific urban area enables us to deduce the succession of facts. Moreover the geological study of outcrops containing rock bodies or features related to human settlement allows us to determine the sequence of historical facts.

## 6. Discussion and concluding remarks

Human-influenced sedimentary bodies and rock mechanical modifications may be divided into three new categories of lithoanthropogenic units:

*Natural lithoanthropogenic units (NAU)* are defined in accordance with the following characteristics:

- Deposits of sedimentary origin controlled by flow variations that contributed to the accumulation of sediments.
- The boundaries of these units, which were generated by hydraulic variations, are attributed to autocyclic controls.
- These units contain materials and artefacts of human origin e.g. prehistoric axes, ceramic fragments ...etc. that can act as clasts (Fig. 3).

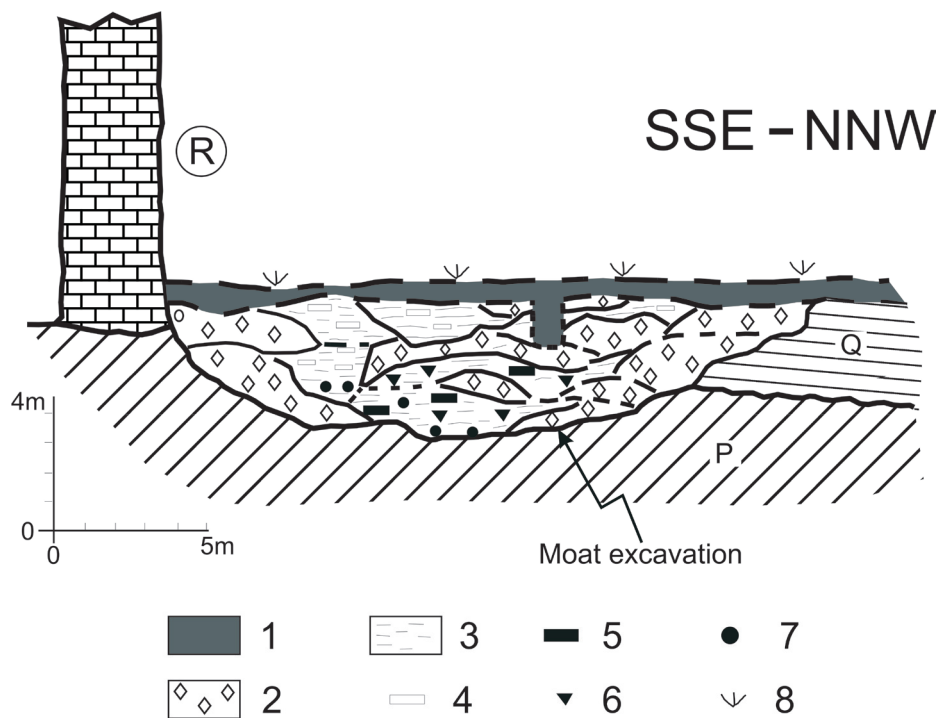


Fig. 5.- Sketch of the archaeological open pit in the Cathedral Avenue, showing the infill of the moat of the Roman wall. 1, recent debris (XVIII-XX Centuries); 2, brick and ceramic fragments; 3, muds; 4, piece of rubble; 5; wood and charcoal fragments; 6, grape seeds; 7, iron nodule, 8, present level of the Cathedral Avenue; P, Pliocene; Q, Late Quaternary; R, Roman wall. The accumulation of artificial debris such as rubble, ceramic fragments, coal, wood and iron oxides corresponds to a *constructed lithoanthropogenic unit*.

Fig. 5.- Esquema de la excavación arqueológica de la Avenida de la Catedral, que muestra el relleno del foso de la muralla romana. 1, detritus recientes (Siglos XVIII-XX); 2, fragmentos de ladrillos y cerámica; 3, barro; 4, cascote; 5; fragmentos de madera y carbón vegetal; 6, semillas de uva; 7, nódulo de hierro; 8, nivel actual de la Avenida de la Catedral; P, Plioceno; Q, Cuaternario inferior; R, Muralla romana. La acumulación de detritus artificiales como cascotes, fragmentos de cerámica, carbón, madera y óxidos de hierro corresponde a una *unidad litoantropogénica construida*.

*Induced lithoanthropogenic units (IAU)* are defined in accordance with the following characteristics:

- This accumulation is usually controlled by artificially produced topographic changes, e.g. the medieval walls of the old city of Barcelona (Ciutat Vella). These walls were constructed in the middle of the thalwegs of former ravines and torrents, which resulted in large accumulations of sandy materials.

- The boundaries of these units, which are locally artificial and clearly defined, were a consequence of an obstacle placed across natural currents, e.g. the construction of the eastern pier of Barcelona harbour controlled the development of large sandy accumulation in recent historical times. This area is occupied by the district known as Barceloneta. In other cases, the boundaries are of sedimentary origin.

*Constructed lithoanthropogenic units (CAU)* are defined in accordance with the following characteristics:

- These units are always due to direct human activity.
- Their borders are clearly limited by excavations or deposition of urban waste, building debris, mine rejects,

infilled quarries, dumping of rejected materials, etc.

- Locally, the units correspond to the remnants of buildings of other man-made constructions.

Despite the difficulty in defining these units, we suggest that researchers on the Quaternary consider the new lithoanthropogenic units proposed that can facilitate the study of recent sedimentary accumulations.

The NAUs display some artefacts that are older than the age of the deposit because they are reworked from former deposits

The NAUs and IAUs are reasonably well stratified and resemble classic lithostratigraphic units. However, the IAUs are usually associated with some kind of construction (dams, piers, etc.) or modification of the landscape (torrent diversion) by humans. Thus, their basal contact could be a non-conformity developed over the former natural deposits.

The CAUs commonly include materials that are the same or nearly the same age as the deposit. Locally, they may contain older materials dumped by humans. The CAUs usually lack stratification and are lithologically

heterogeneous. These units consist mainly of man-made materials (bricks, rubble, garbage, etc.) and display a characteristic lack of stratigraphic continuity as a consequence of irregular periods of dumping.

In view of the above findings, the following considerations should be taken into account:

(A) It is essential to establish the stratigraphic succession of the materials found in wells and excavations. This is not always easy given that the elementary law of stratigraphy (the order of superposition indicates the chronological order of sedimentation) is often inapplicable. Reworked and introduced materials can usually be attributed to human settlement. Extreme caution should be adopted in the analysis of the outcrops in order to avoid misinterpretation.

(B) Correlation should be used to determine the chronostratigraphic unit to which the material found in a specific outcrop corresponds.

(C) Different episodes of continuous and/or interrupted settlement of the city should be determined. Human presence with its variable impact on pre-existing rock bodies should be more clearly defined.

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