

## **A NEW APPROACH TO ANALYZING GROUNDWATER THROUGH ITS MANIFESTATIONS IN THE LANDSCAPES AND TOPONYMY: "SUBTLE" HYDROGEOLOGY**

**Fermín Villarroya**

Departamento de Geodinámica,  
Facultad de Ciencias Geológicas, Universidad Complutense,  
C/ José Antonio Novais, 12. 28040 Madrid, España  
ferminv@ucm.es

**Alejandro J. Pérez-Cueva and Ghaleb Fansa**

Departamento de Geografía,  
Facultad de Geografía e Historia, Universidad de Valencia,  
Avda. Blasco Ibáñez, 28. 46010 Valencia, España  
Alejandro.Perez@uv.es; ghaleb.fansa@uv.es

**Abstract:** "Subtle Hydrogeology" refers to the set of groundwater manifestations and processes in minuscule aquifers in a particular land area that, in many cases, involve human and social dimensions. These are apparently insignificant features, but they conceal the ancient secrets of groundwater and the landscape. Groundwater associated with multilayer low-permeability formations with little saturated thickness hardly has any commercial value. It is, however, a valuable resource for traditionally rural societies, and has given rise to a wide range of ecological, cultural, heritage-related, and toponymic manifestations. These manifestations are studied here in the upper Alfambra basin (Teruel, Spain), from both a geological and a hydrogeological perspective, and from the viewpoint of culture and heritage (with springs, seepages and specific toponymy). For this novel view which contemplates and studies the relationship of groundwater and the landscape, expressed through a specific toponymy (hydronymy), the term "subtle hydrogeology" will be used.

**Keywords:** Subtle hydrogeology, Multilayer aquifer, Alfambra, Hydronymy, Water and landscape.

**Resumen:** “Hidrogeología sutil” se refiere al conjunto de manifestaciones y procesos del agua subterránea de acuíferos minúsculos en un área particular que, en muchos casos, involucra dimensiones humanas y sociales. Son características aparentemente insignificantes, pero encierran antiguos secretos de la relación agua subterránea y paisaje. El agua subterránea, en formaciones multicapa de baja permeabilidad con poco espesor saturado, apenas tiene valor comercial. Sin embargo, es un recurso valioso para las sociedades rurales tradicionales, y ha dado lugar a una amplia gama de manifestaciones ecológicas, culturales, patrimoniales y toponímicas. Estas manifestaciones se estudian en la cuenca alta del Alfambra (Teruel, España), desde una perspectiva tanto geológica como hidrogeológica, y desde la cultura y el patrimonio (manantiales, surgencias y toponimia específica...). Para esta nueva visión, que contempla y estudia la relación entre el agua subterránea y el paisaje, expresada a través de una toponimia peculiar (hidronimia), se utilizará el término “hidrogeología sutil”.

**Palabras clave:** Hidrogeología sutil, Acuífero multicapa, Alfambra, Hidronimia, Agua y paisaje.

## 1. Introduction

It is important to explain the terms landscape, subtle perception, and hydronymy, used throughout this paper. With respect to the landscape, the European Landscape Convention (2000) puts an emphasis on its perceptible dimensions, and defines landscape as “...an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors”. Since landscape involves a subjective experience, it encompasses a perceptible, artistic and existential meaning (Antrop, 2005). The landscape is defined by the Canadian school of architecture as a person’s perception of the land (CSLA, 2014). Most of the natural landscapes have been modified by human activities; hence, they are embedded with symbolic meanings of our societies’ cultural diversity and identity (Swanvick, 2002; Cakci-Kaymaz, 2012). On the other hand, a dictionary definition of ‘subtle’ is something “so delicate or precise as to be difficult to analyze”. Finally, hydronymy is the area of toponymy which studies the origin and meaning of the names of rivers, lakes, seas and, by extension, of springs and characteristic features of groundwater. How all of these are applied to groundwater is the subject of this article.

The relationship between groundwater and landscape is not a new topic, and significant references are found around the world as well as in Spain. A Google search of “landscape features and groundwater” results in 92,100 references, but none of them incorporates the type of analysis or approach that we make in this essay, hence its novelty. The most similar papers to what is presented in this paper are perhaps those re-

lated to groundwater and ecosystems (González-Bernáldez *et al.*, 1987, 1989; González-Bernáldez 1992; Villarroya, 1993; Winter and Llamas, 1993; D'Odorico and Rodríguez-Iturbe, 2009; Temea *et al.*, 2008; Custodio, 2010). Other approaches focus on the geomorphological actions related to groundwater (Higgins and Coates, 1990; Sophocleous, 2002), although here a new approach offers a view of groundwater as part of the geological and geographical landscape heritage. The groundwater features presented and described here may seem irrelevant at first. However, they are key to understanding the ancient secrets of groundwater and the landscape. They also give rise to a richly varied local toponymy, which cannot be easily extrapolated to other places where they are described using different names. These features, although of little importance from the viewpoint of applied hydrogeology, are a rich repository of traditional water lore that the local people have always known how to appreciate and use.

The methodology of this article was based on an exhaustive work of cataloging the springs of Monteagudo del Castillo and Allepuz and analyzing their hydrogeological contexts. During the field work, a series of aspects of the landscape that were closely linked to the emergence of groundwater flows (mostly minuscule) were also observed and analyzed. These particular features have been known and used for centuries by the local shepherds and farmers leading to a unique hydronymy, or water-related toponymy. However, there is a danger that these names will be lost as they fall into disuse in these now largely uninhabited mountains.

The main objectives of this article are several. On the one hand, recognize the conspicuous, but often semi-hidden, value of these distinctive landscape features and make them known. Subsidiarily, encourage to discover in other regions hydronyms linked to the territory. More specifically, the article focuses on explaining the meaning of a few landscape features found in the upper basin of the Alfambra River (chumarral, clote ...).

## 2. Geographical and geological characteristics of the study area

The area analyzed for this case study (Fig. 1) is located in the upper basin of the Alfambra river in Teruel (Spain) and includes the municipal areas of Allepuz and Monteagudo del Castillo. This is a mountainous area and the villages in both municipalities are at an altitude of around 1,425 m a.s.l. The mean precipitation is 450-500 mm/year, and the annual mean temperature is around 10°C (Peña *et al.*, 2002; Penalba and Pérez-Cueva, 2013). The Alfambra river is the only perennial stream (although some inter-annual dry episodes do exist). The western zone is drained by the Río Seco (Dry River) where the toponym itself reflects a lack of water. This region is largely uninhabited. There are 52 and 128 inhabitants in Monteagudo del Castillo and Allepuz, respectively (INE, 2017), although this figure can triple during summer months. There are still some traces of traditional farming activities with flocks of sheep and grain cultivation, as well as new activities such as pig farming and incipient truffle cultivation.

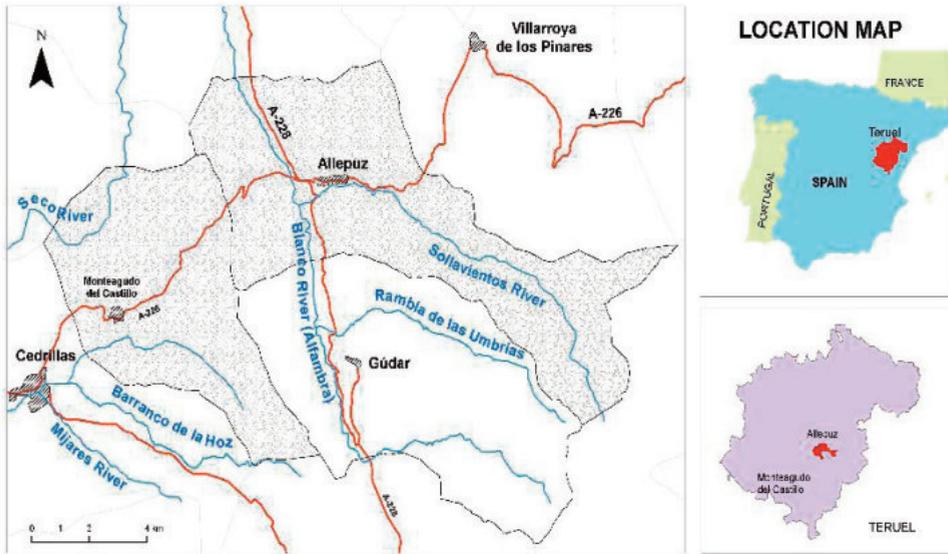


Figure 1. Location of the study area.

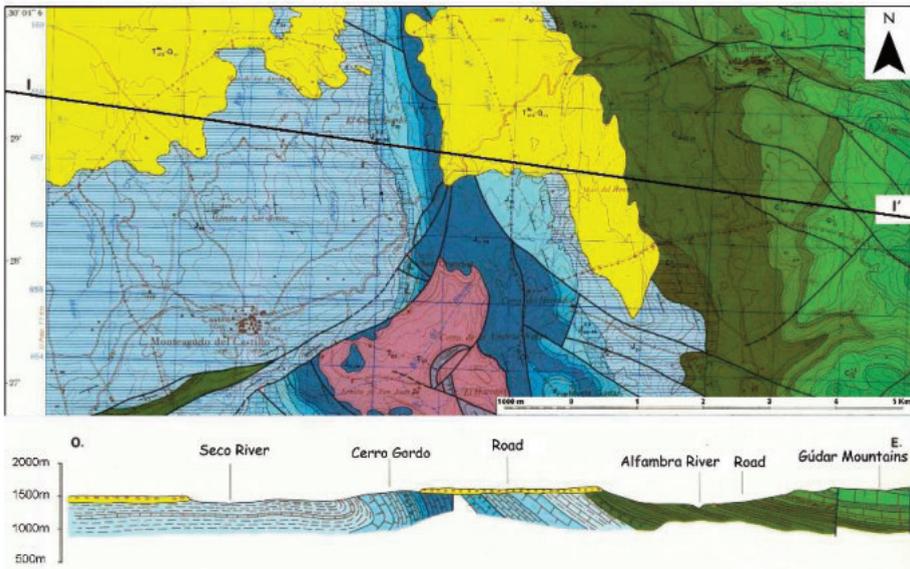


Figure 2. Geological profile of the study area, showing Jurassic materials (in blue) in Monteagudo del Castillo, and Cretaceous materials (in green) in Allepuz. The pink color indicates Triassic materials, while yellow color refers to Neogene materials (Gautier, 1981).

From a geological point of view, the zone is characterized by two very different areas. In the eastern sector, in the Allepuz district, there are outcrops of lower Cretaceous materials in Weald facies formed by alternating layers of clays, silts and sandstones. In contrast, in the Monteaugudo del Castillo district, to the west, there are outcrops of marine upper Jurassic limestone, marl, and calcarenite partially covered by Neogene materials (Simón-Porcar et., al 2018, 2019). They are found as sub-horizontal strata in the central part, while strong buckling has produced inverted stratigraphical sequences at the eastern edge (Gautier, 1981) (Fig. 2).

### 3. Landscape features linked to the presence of groundwater

#### 3.1. The 'multilayer aquifer' of the Weald facies

The "multilayer aquifer" is not a true aquifer, defined as a body of permeable rock which can contain or transmit groundwater in significant amounts. The stratigraphic arrangement of the Weald facies series, formed by alternating layers of clays, silts and sandstones, defines a multilayer but low-permeability aquifer. A careful examination of the western slope of the Alfambra valley reveals seepage that is the result of existing permeable sandstone layers interbedded with clays and silt. The latter act as small impermeable local layers probably without lateral continuation. Where these outcrops are sufficient to allow the emergence of groundwater, it is usually associated with very weak flow rates. These outflows are fairly constant over time, even in drought periods, because they drain through layers with fairly low permeability. This makes them of interest both to herders and to the wild fauna, as they are almost permanently wet.

The main groundwater features of this landscape are known as *enjuagadores* ("rinses"; Figs. 3 and 4), which refers to an area where the groundwater emerges with a flow rate enough to require drainage to allow farming. Sometimes, the local farmers construct *caños*. This is an example of a locally used term that describes places where subterranean land drainage is managed by digging deep ditches and burying drainage pipes, or by simply filling it with boulders which are then also buried.



Figure 3. Examples of *enjuagadores*. Left bank of the Alfambra in the Allepuz area.

The toponym *benar*, also from one part of this sector, refers to an area where water regularly pools up, resulting in areas well suited for hay, coinciding with the *chumarrales* (marshy land with seepage, Fig. 4, 5 and 6). The *enjuagadores* described above are used to drain the excess water from this land. Another toponym found on the western bank of the Alfambra river is *clote* (Fig. 7). This term is used by the local people for an enclosed, hollow or topographic depression with grass growing at its bottom. This is conditioned by the concealed presence of groundwater, either as the result of a single impermeable base, or because this is where the runoff gathers from one or more *chumarrales*. The result is an advantageous meadow ecosystem, with fresh grazing, as well as serving as an excellent ecological niche for collecting fungi, which are highly prized in this area.

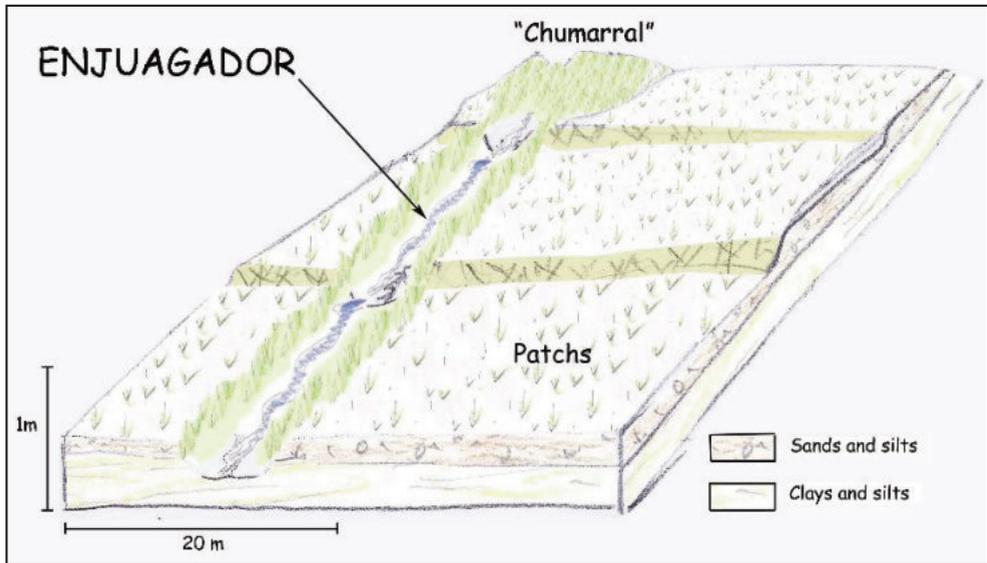


Figure 4. Diagram showing an *enjuagador* draining to a *chumarral*.

The topological groundwater features included in this “subtle hydrogeology” once supported small watering holes, providing enough water to the smaller sheep herds of the past and the scattered houses and farms nearby.



Figure 5. Example of *chumarral*. Western bank of the Alfambra river.

### 3.2. The “multilayer aquifer” of the Purbeck Jurassic materials

The Tithonian-Berriasian Jurassic series in the area, in Purbeck facies, are tectonically deformed. Beds show a sub-horizontal dip at the nucleus of a syncline, but they are nearly vertical or inverted at its eastern limb. It presents strongly inflected layers producing inverted dips (Fig. 2). The presence of alternating layers of marls, sandstones, clays, limestones and silts, in which the finest materials act as local impermeable base levels for the groundwater flow, along with the position of the emergence points on the land surface, lead to the numerous springs (Pérez-Cueva *et al.*, 2014) and seepages that have been studied in detail by Penalba and Pérez-Cueva (2013). Another type of modest sources is those that appear in the contact between the Purbeck marls and the cover of Neogene materials (Penalba and Pérez-Cueva, 2013). These sources have very low flow rates, normally less than 0.07 l/s, and occasionally dry up completely.

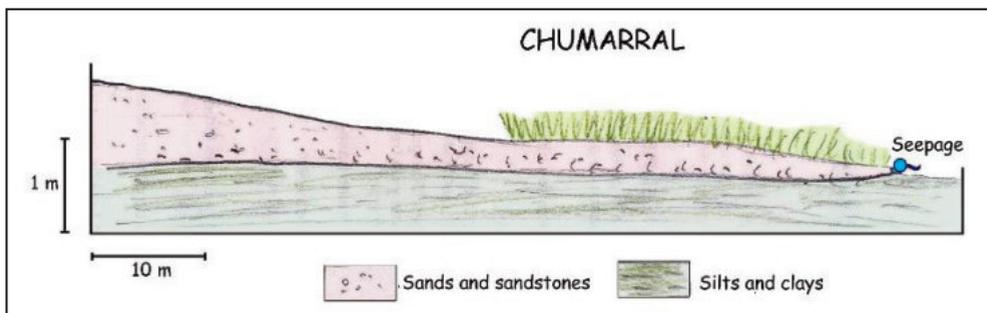


Figure 6. Diagram of a *chumarral*. West bank of the Alfambra river.

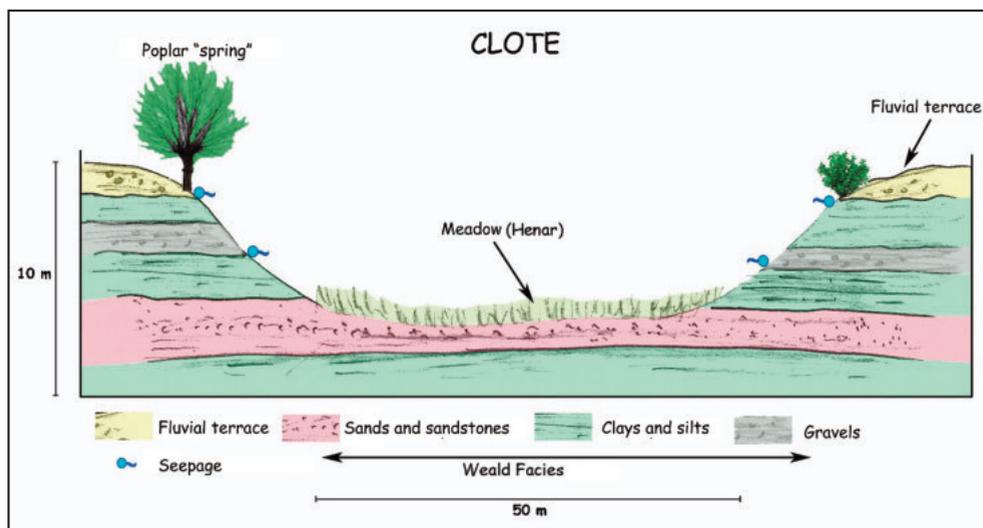


Figure 7. Diagram of a *clote* which produces a hay meadow or *henar*.

*In situ* analyses of these springs, such as those carried out by Penalba and Pérez-Cueva (*ibid*), reveal the hydrogeological framework that explains their origin and permanence. In many cases such origin is simply due to constant seepage. For example, the “*Mas de Cipriano*” and “*La Pinilla*” springs result from the stratigraphic contact between permeable limestones and impermeable underlying marls (Fig. 8).

The origin of the springs known as “*La Cavada*”, “*Arriba de la Fuente Vieja*”, “*Huerto del tío Tiburcio*” and “*Huerto del Bastero*”, among others, is the same (Fig. 9). For a conventional planning of ground water resources, these springs and seepage points are insignificant or irrelevant. However, this is not the case for the traditional local culture and for the current small farming settlements that depend on this water supply for household and livestock use.

#### 4. Environmental value and services provided by “subtle” hydrogeology

Mountains of the Iberian Chain are rich in springs (Pérez-Cueva *et al.*, 2014), due to their varied geology and frequent lithological contrasts. Traditionally, rural societies knew how to make the best use of this natural resource according to the requirements of farming and raising livestock. Therefore, the seepages and springs have always represented a unique value in the heritage of this area and still make a part of the local geography.

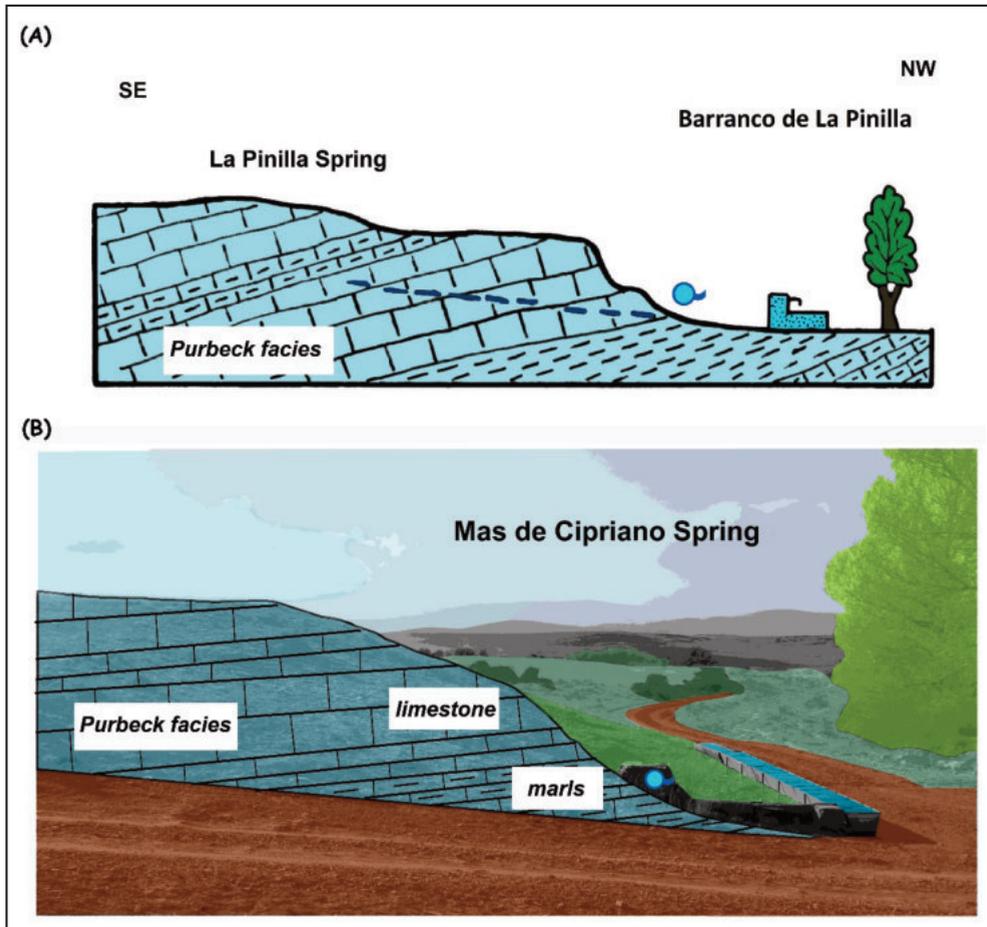


Figure 8. Hydrogeological diagrams of *La Pinilla* (A) and *El Mas de Cipriano* (B) springs. (From Penalba and Pérez-Cueva, 2013). (*Pinilla*, *Mas de Cipriano*, *Barranco de la Pinilla*, are geographic local names).

In the small area of the municipal districts of Monteagudo and Allepuz (*ca.* 110 km<sup>2</sup>) a wide range of these water resources can be found with various adaptations and uses. Another simple, common way used to dry out the *chumarrales* was to plant poplars (*chopos de manantial*) (Fig. 7). This tree was normally found on the banks of rivers and main irrigation channels, and was specially pruned (with no central stem) to provide wood, building beams, and animal fodder. Wherever it grew on farm land, it facilitated the evapotranspiration of the *chumarrales*, thus reducing outflow and, at the same time, providing shade and a microclimate to allow the farm workers a well-earned rest from the hard labour of agricultural tasks in the past.

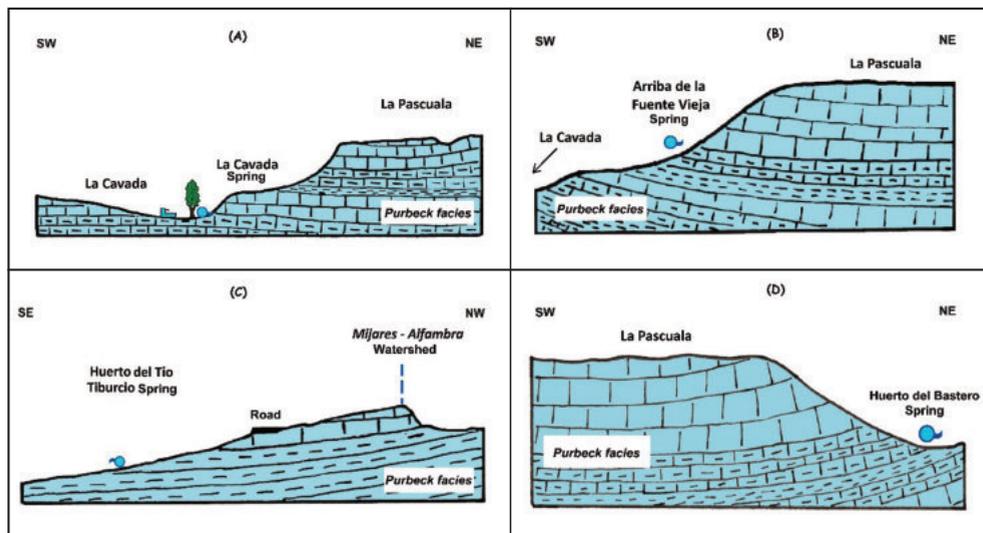


Figure 9. Hydrogeological diagrams of Purbeck facies springs in Monteagudo del Castillo (Teruel). (Penalba and Pérez-Cueva, 2013). (*Huerto tío Tiburcio, la Pascuala, La Cavada, Huerto del Bastero*, are geographic local names).

This wide variety of water resources found in different geological formations is natural, although they are sometimes adapted to best suit the needs of inhabitants. These water systems can be considered as a service in which groundwater is utilized by local wildlife and small human settlements as an *in situ* water supply. According to Bocanegra *et al.* (2012), a service provided by an ecosystem is understood to be ‘the function or process which occurs naturally in an ecosystem and is made use of in some way by human beings’. Therefore, the forms of groundwater analyzed here from the viewpoint of “subtle hydrogeology” provide a valuable service.

## 5. Conclusion and proposal

Since the early 1970s there have been various new approaches to the assessment and management of natural resources (Schumacher, 1973; Boff, 2003; Villarroya, 2004). Clear examples of these, in Spain, include the New Water Culture (NCA, 2005) and the manifesto “Geology for a new Culture of the Earth” (Villarroya *et al.*, 2012), to mention only two cases. Groundwater must not be left out of this trend.

Although often hidden from sight, groundwater is closely related to certain features of the landscape which reveal its subtle presence. The particular features and value of

these groundwater systems are not normally focused on by hydrogeologists or scientific journals. This is, nevertheless, the rationale for traditional uses and a wealth of hydronyms, which are now in evident decline due to lack of use and/or loss of traditional ways of life caused by the declining population and also in part by the new occupation of these areas by migrant workers with no local roots. Our proposal is to use the term “subtle hydrogeology” for this new approach that describes the relationship of groundwater with local land, often shown through hardly perceptible seepage and springs with their own particular hydronymy. We hope to encourage others to bring these hidden aspects of groundwater resources to light, to study and catalogue them, and to reapply this methodology to similar areas. This could result in a better understanding of these ecosystem services as a resource to be conserved and protected, and to make the general public more aware. This new way of looking at aquifers may also help to describe regional toponymy in other locations which are also closely related to the latent presence of groundwater. The proposal put forward here is to include this “subtle hydrogeology” as a new environmental landscape factor to be taken into consideration within the geological and geographical heritage.

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