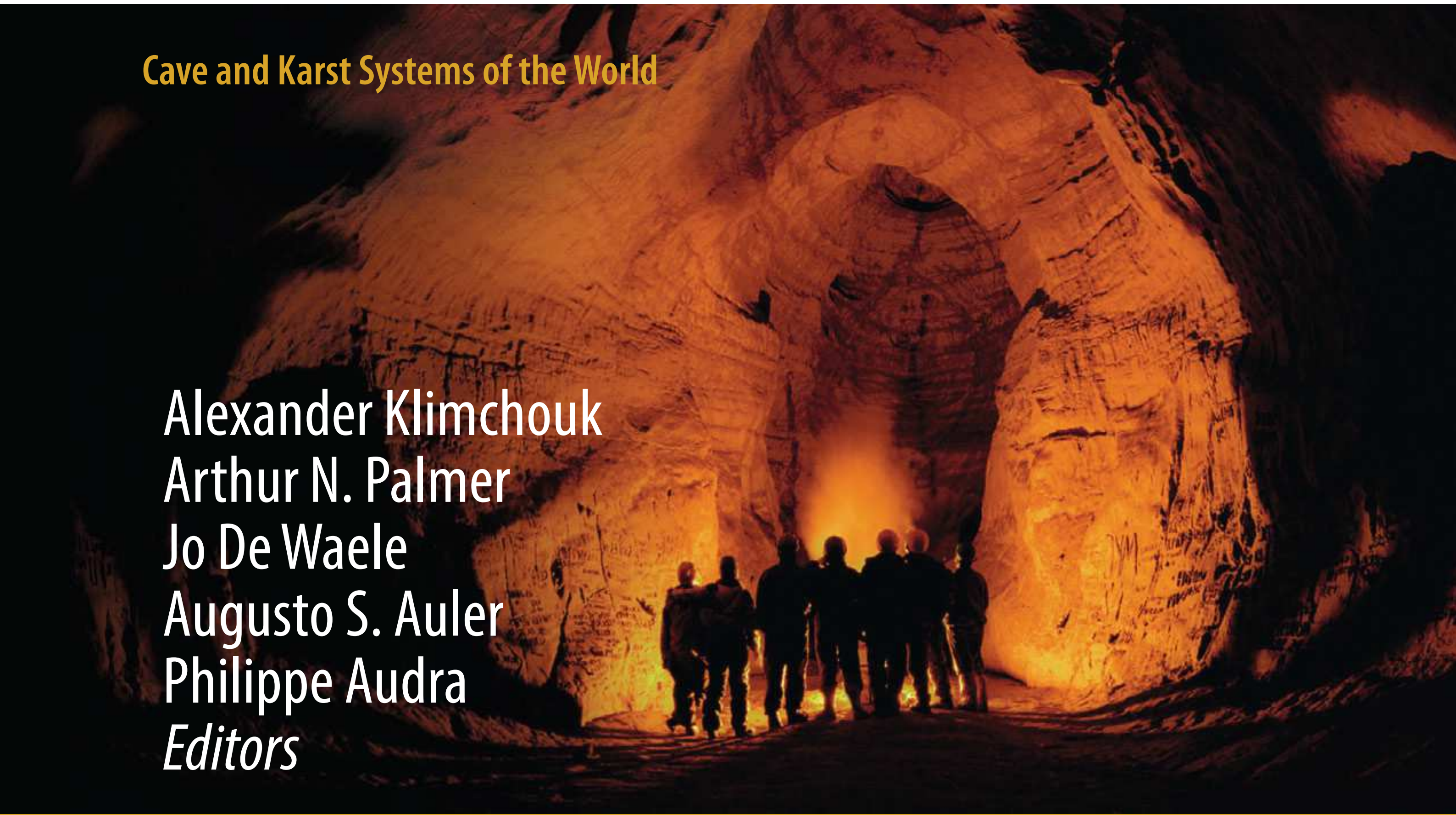

Cave and Karst Systems of the World

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Hypogene Karst Regions and Caves of the World

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Evidence for Regional Hypogene Speleogenesis in Murcia (SE Spain)

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Fernando Gázquez, José María Calaforra, Tomás Rodríguez-Estrella, Andrés Ros, José L. Llamusí, and Juan Sánchez

Abstract

Signs of hypogenic speleogenesis have been detected in a number of caves of the Murcia Region (SE Spain), in some cases revealing active speleogenetic mechanisms rarely observed in hypogene cavities elsewhere in the world. Here, we investigate the hypogenic morphologies and speleothems of four caves in this region, namely Sima de la Higuera, Sima Destapada, Cueva del Agua and Cueva del Puerto. Also, other ten caves showing evidence for hypogenic speleogenesis has been preliminary described. Processes related to ancient and current hydrothermal activity, the discordance of permeability structures in the adjacent beds and the spatial arrangement of the regional hydrogeology have given rise to maze patterns and typical subaqueous hypogenic morphologies. These include spongework mazes, rising wall channels and shafts, feeders, bubble trails, solution pockets, megascallops and rising of chains cupolas, among others. Carbonic acid speleogenesis is responsible for the formation of most of these cave features; however, evidence of sulfuric acid speleogenesis (SAS) has been observed in Cueva del Puerto and Sima del Pulpo, which host massive secondary gypsum deposits. Speleothems typically linked to hydrothermal water upwelling and CO_2 degassing close to the water table are present in most of these cavities, including folia, calcite spar crystals, cave clouds, calcite rafts deposits and several types of cave raft cones. The wide variety of hypogenic speleogenesis indicators and speleothems whose genesis is unconnected to meteoric water seepage reveals that the hydrothermal field of the Murcia Region hosts one of the densest active hypogenic subterranean networks in the world.

Keywords

Hypogenic caves • Hydrothermal speleogenesis • Hydrothermal speleothems

1 Introduction

The Murcia Region is located in the southeastern margin of the Iberian Peninsula, being the most hydrothermally active regions of Spain. Despite limited surface water resources (less than 400 mm of annual precipitation) this region hosts extensive karstic aquifers that have been historically exploited for agricultural purposes. Indeed, many aquifers in this region are hydrothermal, with temperature exceeding 40 °C (Fig. 1), so some of their waters have been traditionally used to supply thermal baths (Pinuaga-Espejel et al. 2000). Groundwater overexploitation over the past 50 years has produced dramatic lowering of the water table on a regional

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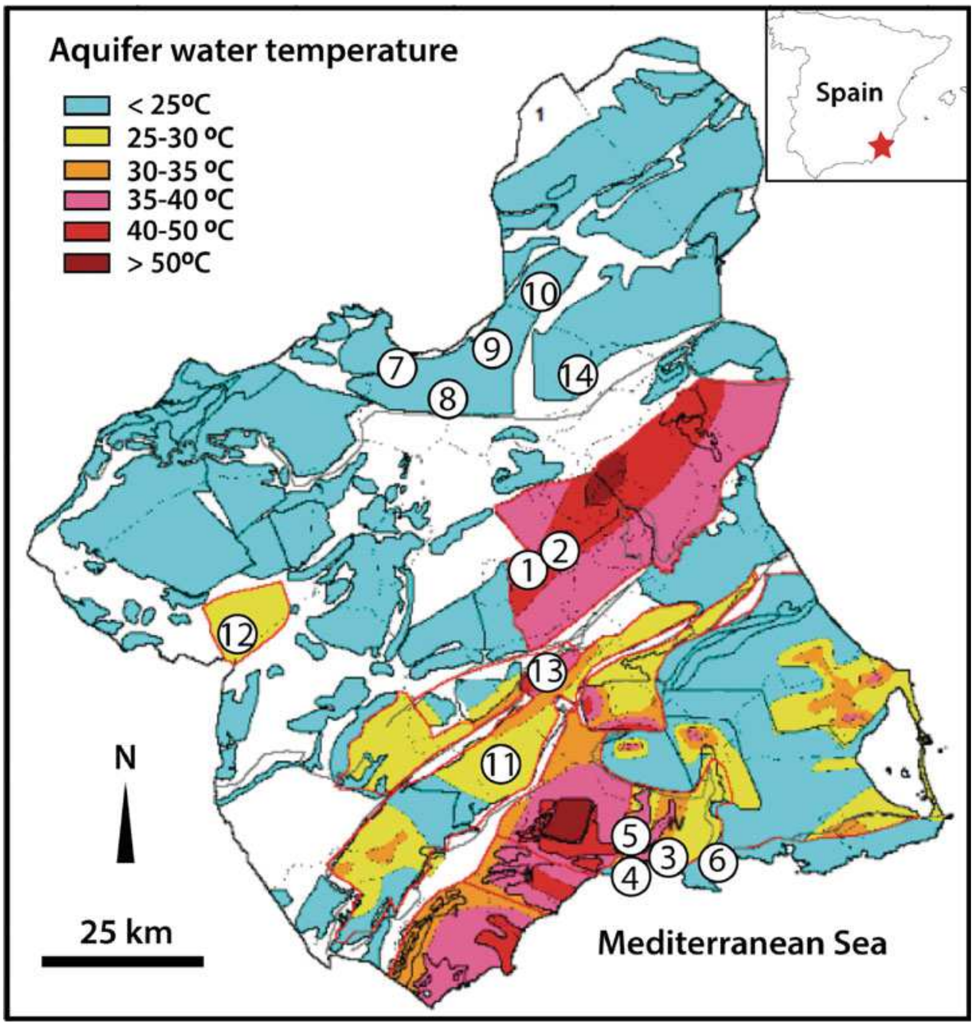


Fig. 1 Location of Sima de la Higuera (*1*), Sima del Almez (*2*), the Sima Destapada (*3*), Cueva del Agua (*4*), Cueva de la Plata (*5*), Cueva del Gigante (*6*), Cueva del Puerto (*7*), Sima del Pulpo (*8*), Sima de Benis (*9*), Cueva del Pozo (*10*), Cueva del Agua-Lorca (*11*), Cueva de Luchena (*12*), Sima del Vapor (*13*) and Cueva de la Almagra (*14*). The temperature of the modern aquifer waters is given (after Rodríguez-Estrella 2005)

scale, which has allowed access to several phreatic caves that were previously flooded (Ros et al. 2011, 2014a, b).

The lack of relationship between subterranean morphologies and seepage water from the surface can serve as a criterion for identifying hypogenic caves. However, relict or fossil hypogenic features can be easily masked by sediment accumulation or overprinted epigenic elements, especially in humid climates. These traits have motivated the search for recognizable signatures of hypogenic speleogenesis that allow clear identification of this kind of caves.

Recent studies have proposed a series of indicators to flag hypogenic caves, including morphological features and characteristic speleothems (Audra et al. 2009; Klimchouk 2009; Palmer 2011; among others). This includes the model of morphologic suite of rising flow (MSRF) proposed by Klimchouk (2007) that has been widely applied to characterize hypogenic caves. It is based on the identification of a set of so-called hypogenic patterns that result from water upwelling, usually thermal fluids. These features can be split into three categories: (1) inlets of ascending flow into the system (feeders), usually located at the bottom of chambers and master passages; (2) transition wall and ceiling features that connect the cave levels with upper passages (usually ceiling domes, channels and solution pockets); and (3) upward leakage structures (outputs), typically located on the ceilings of upper cave levels.

In addition, the presence of speleothems formed under subaqueous conditions from a solution that was highly saturated in calcium carbonate can provide evidence of the hypogenic origin of caves. Nevertheless, it is worth mentioning that the occurrence of these types of speleothem is not restricted to hydrothermal caves but has also been described in non-thermal, epigenic caves (D'Angeli et al. 2015), where high saturation in calcite is reached due to elevated production from plants, as well as intense CO_2-degassing and evaporation in the cave.

In the Murcia Region, these distinctive patterns are widespread in many caverns that have recently been suggested as having a hypogenic/hydrothermal origin (Ros et al.

2011, 2014a, b; Gázquez et al. 2016a, b). These caves accommodate a wide variety of speleothems usually related to hydrothermal flows. In the present study, we sum up the investigations conducted over the past 5 years in Sima de la Higuera, the most renewed hypogenic cave in the Murcia Region because of its outstanding hypogenic morphologies and speleothems (Gázquez et al. 2012; Gázquez and Calaforra 2013a, b). In addition, we selected two of the most important karstic complex in this region, the Sima Destapada-Cueva del Agua System and Cueva del Puerto, for preliminary description and morphological analysis. Moreover, other smaller caves, also hypogenic in origin, have been investigated. This includes Cueva del Gigante, Sima del Almez, Sima de Benis, Cueva del Pozo, Sima del Vapor, Sima de la Plata, Cueva de la Almagra, Cueva del Agua-Lorca, Cueva de Luchena and Sima del Pulpo. It is worth mentioning that most of these caves still show positive thermal anomalies with respect to the mean external temperature (~18 °C) (Table 1). This provides further evidence of the hypogenic/hydrothermal processes in these caves, which are still active in some cases.

2 Regional Geological and Hydrogeological Setting

The geology of the Murcia Region comprises materials of the Betic Mountain range that run from the Gibraltar strait to the Balearic archipelago. This mountain chain represents the westernmost edge of the Alpine Orogeny. In the Murcia Region, the three main domains of the Betic mountain range (Prebetic, Subbetic and Betic) are present. The Prebetic domain crops out in the NW part of the region, mainly comprising Cretaceous limestone and dolostone, and dolostone and marls of Paleocene and Eocene Ages. The Subbetic domain contains Jurasiss limestone and dolostone, clays and Triassic gypsum deposits. The Betic comprises phyllites, schists and micaschists of the Maláguide, Nevado-Filábride and Alpujárride. These metamorphic materials serve as impervious basement to the aquifers most parts of this area. In general terms, Triassic limestones and dolostone with different degrees of metamorphisms and subsequent karstification constitute the aquifer units that, in some cases, are topped by impervious/aquitards materials (e.g., Tortonian or Liassic marls and calcoschists). These acted as the confining upper layer for the hypogenic aquifers in some cases.

The geothermal fluxes in the Murcia Region are intrinsically linked to neotectonic events, the presence of deep faults and distensive tectonic movements, all controlled by the relative movements of the Euroasian and African plates (Rodríguez-Estrella 2005). Indeed, this is the most seismically active region of Spain and the epicenters are aligned along the main regional faults, which include the Alhama, Baños, and Murcia-Cartagena Faults, among others, most located in the SE sector of the region. Volcanic events during the Upper Pliocene-Pleistocene (2.8–1 Ma) are responsible for part of the hydrothermal anomalies observed in this area. In some cases, volcanic phenomena were associated with post-orogenic basin sedimentation and the relative thinning of the earth's crust (Pinuaga-Espejel et al. 2000). Modern hydrothermalism is especially active in the SE and central parts of the region, with groundwater temperatures that exceed 50 °C in some cases (Fig. 1).

3 Hypogenic Caves in the Murcia Region

3.1 Caves of Sierra Espuña Mountain Range

Sima de la Higuera (Fig Tree Cave) is located in the Sierra de Espuña mountain range, in the municipal district of Pliego. Its entrance lies at 485 m a.s.l. Speleological exploration of the cave began in 1997, although there is evidence that it was discovered earlier than this date (Cuatro Pico Club and Pliego Espuña Club 2001). Its surveyed length is 5500 m and its deepest part is 156 m below the cave entrance (82 m below the base of the entrance shaft) (Fig. 2a). The cave is located in the Malaguide complex of the Betic domains and has formed, in ascending order, within calcarenites and dedolomitized calcarenites, calcareous microconglomerates and slightly dolomitized limestones of Oligo-Miocene Age. The carbonate sequence is quite fractured due to NW-SE pressure that caused a series of joints and faults, which subsequently determined the cave's morphology, particularly in its deeper levels. Significant hydrothermal springs currently arise in the vicinity of the cave, with temperatures of around 32 °C (Rodríguez-Estrella 2015).

Typical features of phreatic speleogenesis such as scallops and megascallops, appear in this cave, especially in the upper levels above the −85 m level. Furthermore, dissolution forms like bubble trails and alteration calcite crusts (Fig. 3b) are seen above the −85 m level. A 10-m-long diaclase along the floor of Paradise Chamber (−98 m) seems to have acted in the past as a feeder of deeper thermal water into this cave level. The hydrothermal dissolution of the bedrock occurred preferentially along fractures, giving rise to labyrinthine passages (a three-dimensional "maze cave") that are typical of hypogenic caves and which are especially well-developed in Sima de la Higuera (Fig. 2a) (Gázquez and Calaforra 2013a, b; Gázquez et al. 2016a, b).

Sima de la Higuera accommodates most of the typical speleothems described for hypogenic caves, including calcite spars (which fill fractures in the bedrock), cave clouds, folia and calcite raft cones (Fig. 3) (Gázquez and Calaforra

Table 1 Hypogenic features in caves in the Murcia Region

	Higuera	Almez	Destapada	Agua-Cartagena	Plata	Gigante	Puerto	Benis	Pulpo	Pozo	Luchena	Agua-Lorca	Vapor	Almagra
Location	Pliego	Pliego	Cartagena	Cartagena	Cartagena	Cartagena	Calasparra	Cieza	Cieza	Jumilla	Lorca	Lorca	Alhama	Fortuna
Length (m)	5500	220	3400	3062	378	610	4389	350	4780	1023	561	546	85	755
Maximum air temperature (°C)	21	n.m	29	30	n.m	21	20	25	21	n.m	n.m	21	43	29
Hypogenic morphologies														
Maze caves	X		X				X				X	X		X
Chimneys	X		X			X	X			X	X	X		
Bubble trails	X	X		X					X			X		
Megascallops	X	X	X	X			X	X	X	X	X	X		
Ceiling pockets	X	X	X			X	X	X		X	X	X		
Cupola and domes	X	X	X	X	X	X	X	X	X	X	X	X		X
Feeders	X	X	X	X		X	X	X?	X	X	X	X	X?	
Pendants	X		X	X		X	X		X			X		
Blind ascending passages	X		X	X		X	X		X	X	X	X		
Partitions	X		X				X							X
Boxwork	X		X	X?		X	X					X		
Micritic crusts	X													
Hydrothermal speleothems														
Cave raft cones	X				X				X?			X		
Cave clouds	X				X			X	X					
Calcite spars	X		X				X		X			X		
Folia	X				X?			X	X					
Calcite rafts	X		X				X		X			X		
Ferromanganese crusts	X		X	X		X	X		X			X		
Gypsum speleothems							X	X	X					

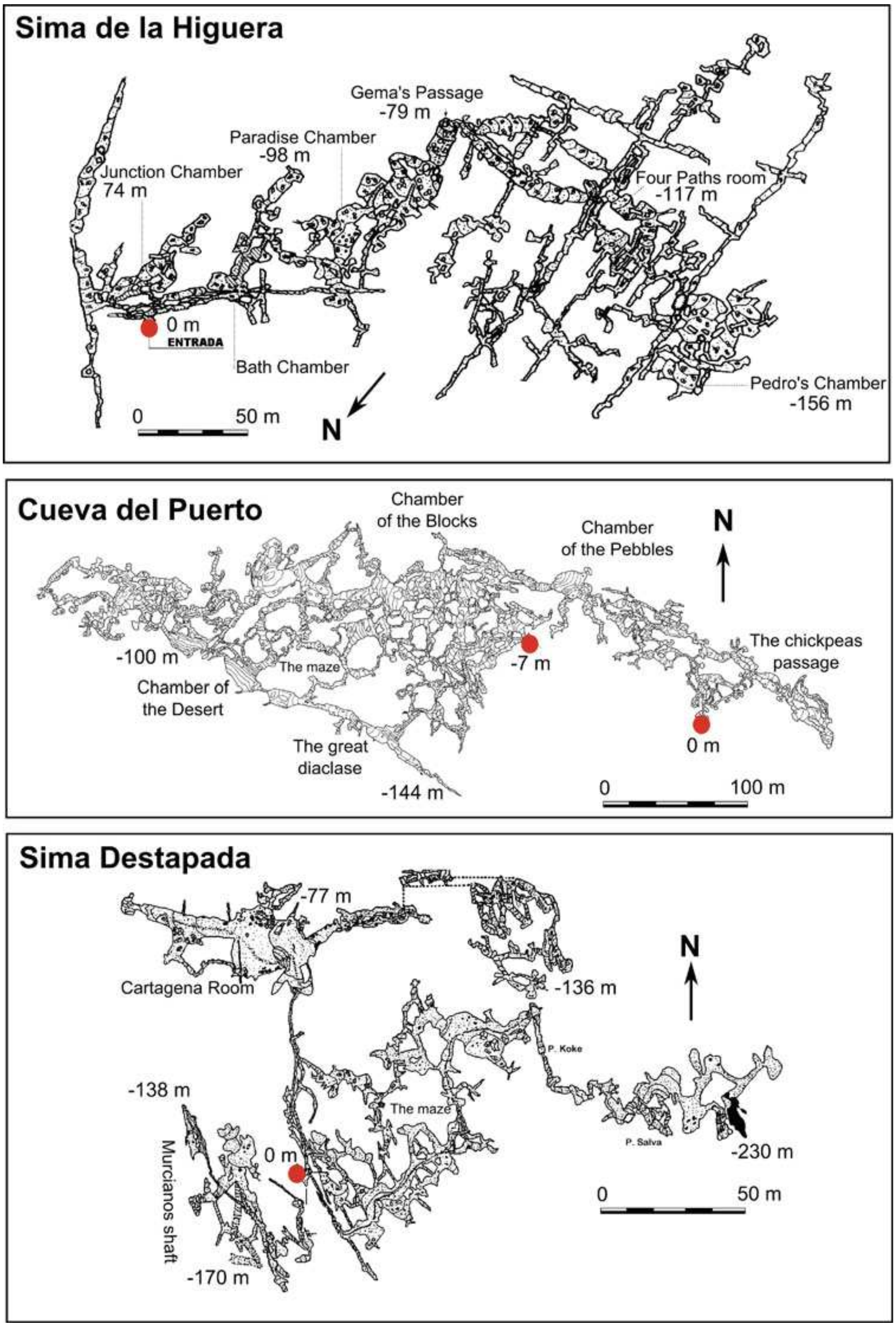


Fig. 2 Topography of the three longest hypogenic caves in the Murcia Region: Sima de la Higuera (Cuatro Pico Club and Pliego Espuña Club 2001); Sima del Puerto (Cuatro Picos Club 1996); Sima Destapada (Ros et al. 1988). The *red circles* indicate the cave entrances

2013a, b). All these speleothems are usually precipitated under phreatic or epiphreatic conditions from water that is highly saturated in calcium carbonate, typical of hydrothermal environment. This cave also exhibits outstanding examples of *boxwork* coated with ferromanganese crusts, whose origin was linked to subaqueous precipitation of hydrothermal calcite in cracks of the hostrock and subsequent mechanisms of corrosion under subaerial conditions (Fig. 3) (Gázquez et al. 2012).

Interestingly, in Paradise Chamber, ninety-two raft cones have been inventoried, displaying two different morphologies: roughly 40% can be considered as tower cones (or simple-tower raft cones), while the remaining 60% have a notch in the middle and look like two cones, one

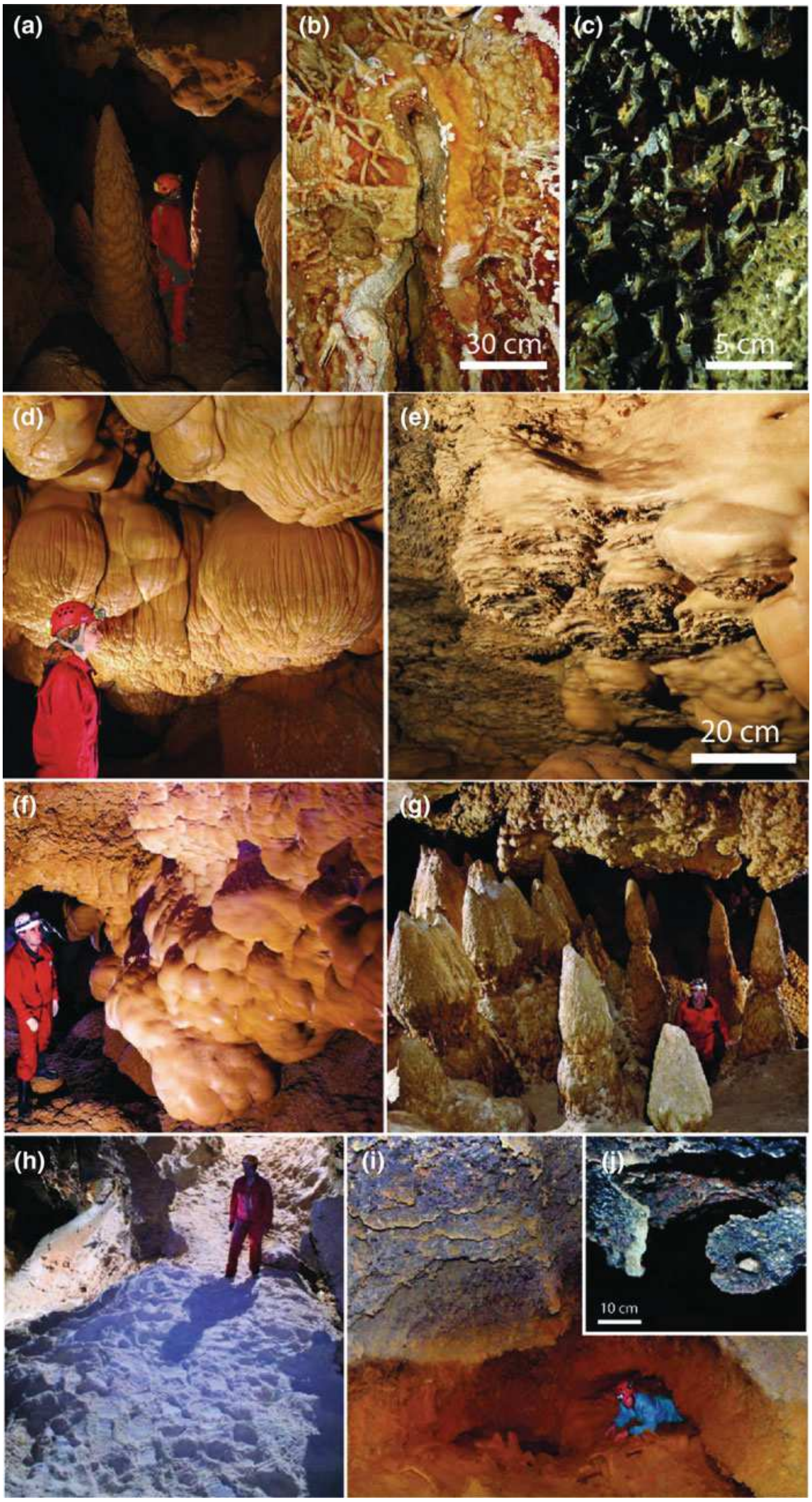


Fig. 3 Speleothems linked to the hypogenic origin of Sima de la Higuera Cave: **a** tower raft cones; **b** bubble trails and boxwork; **c** calcite 'spar' crystals coated with ferromanganese oxihydroxides; **d** cave clouds; **e** folia; **f** cave clouds; **g** double-tower raft cones; **h** piles of calcite rafts; **i** and **j** boxwork and ferromanganese coatings in Manganese Gallery (*Photographs* Víctor Ferrer)

superimposed over the other (Fig. 3). These cones formed in a hydrothermal and epiphreatic environment where dripwater, dripping repeatedly over the same spot, sinks calcite rafts that were floating on the water surface of a cave pool. In particular, the genetic mechanism that gave rise to the double-tower cones also included an intermediate stage of rapid calcite raft precipitation, caused by a drop in the water table and by changes in cave ventilation leading to greater CO_2 degassing and evaporation over the surface of the thermal lake where these speleothems formed. Calcite rafts were deposited in Paradise Chamber, completely covering many of the cones. Later, conditions for slower calcite raft precipitation were restored and some of the cones continued to grow at the same points. When the water table finally fell below the level of Paradise Chamber, the tower cones became exposed, as the incongruent deposits of calcite rafts were dissolved and mobilized to lower cave levels (Gázquez and Calaforra 2013b). Today, calcite raft deposits are scarce in this shallower level (above −82 m) but they do appear at the depth of the Paradise Chamber in Sima de la Higuera, and are especially abundant in deeper passages, such as the Four Paths Chamber (−117 m) (Fig. 3), where numerous calcite raft piles are found (Gázquez and Calaforra 2013a, b).

It is worth mentioning that in the Sierra Espuña mountain range there is another smaller cave (220 m long and 33 m deep), named Sima del Almez. This cave exhibits morphological signs of rising water flow, including linear half-tube structures with smooth surfaces (ceiling half-tubes), solution pockets and ascending chains of scallops that are vestiges of water flows that dissolved the carbonate bedrock (Ros et al. 2015) (Fig. 7).

3.2 The Caves of the Hydrothermal Field of Cartagena

Sima Destapada and Cueva del Agua are located in the Mazarrón Gulf, on the southeastern coast of the Murcia Region, near the town of Isla Plana. The entrance to Sima Destapada is at the top of the Cabezo de Hornos Mountain (285 m a.s.l). It was discovered in 1975 and speleologically surveyed in the 1980s. This exploration produced a precise topographic map, with more than 3300 m of the cave surveyed, extending to a maximum depth of −221 m (Ros et al. 1988). In regard to Cueva del Agua, its natural entrance lies barely 300 m from the shoreline (1 m a.s.l) although no man-size passage connecting the cave with the sea has been found to date. Here, surveys started in the early 1970s and are still in progress. Exploration of this cave has been particularly complex because more than 95% of the cave profile lies below sea level (Ros et al. 2011). Both caves are developed in Triassic marbles, dolostone and limestone. In places, phyllites, quartzite, shales and reddish sandstones of Permo-Triassic age can be found.

Despite being less than 1600 m apart, no connection between the two caves has been found yet (Fig. 4). The deepest emerged level of Sima Destapada lies 221 m below the cave entrance. Beneath that, the cave passages are submerged in thermal water (31 °C) and remain in part unexplored. To date, 400 m of the submerged karstic network has been surveyed. In Cueva del Agua, a freshwater body (7–8 mS/cm) occupies shallower strata (0–6 m deep), overlying a brackish thermal water body (42–43 mS/cm and 30 °C) that has a maximum depth of 20 m. The cave follows the main SE-NW axis, with a surveyed length to date of 3620 m (May-2016).

In Sima Destapada, in addition to the 50 m-deep pits that connect the intermediate emergent cave levels with the hydrothermal aquifer, several blind shafts (without man-sized access to the lower level) are found along the floor of the upper passages. These are distributed in various parts of the cave, and probably acted as feeders in the past (Fig. 5a). In places, dissolution of this wall left pillars where some of the passages have partly disappeared and been incorporated into larger chambers. Pendant-like features, related to the same phreatic dissolution-corrosion

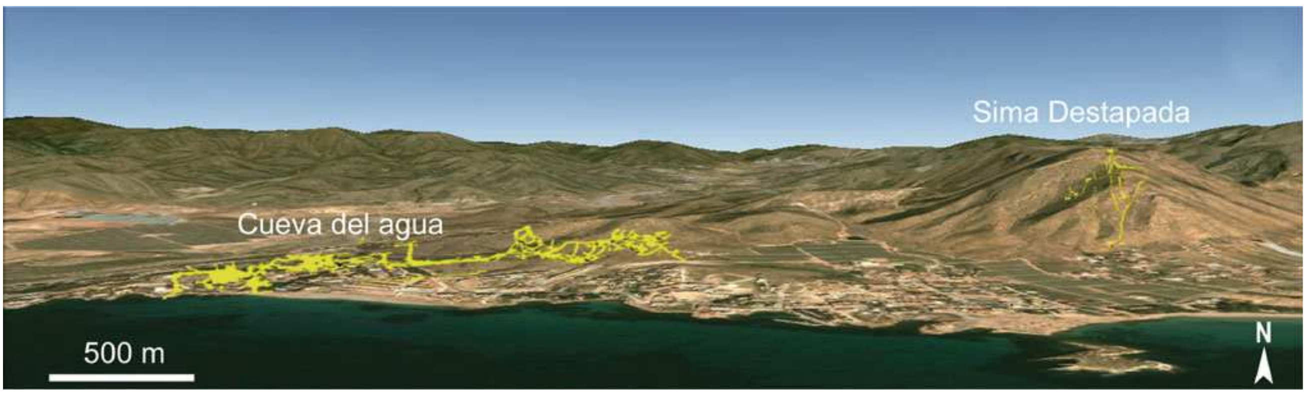


Fig. 4 Topographies of Cueva del Agua and Sima Destapada, located near the village of Isla Plana (Murcia Region)

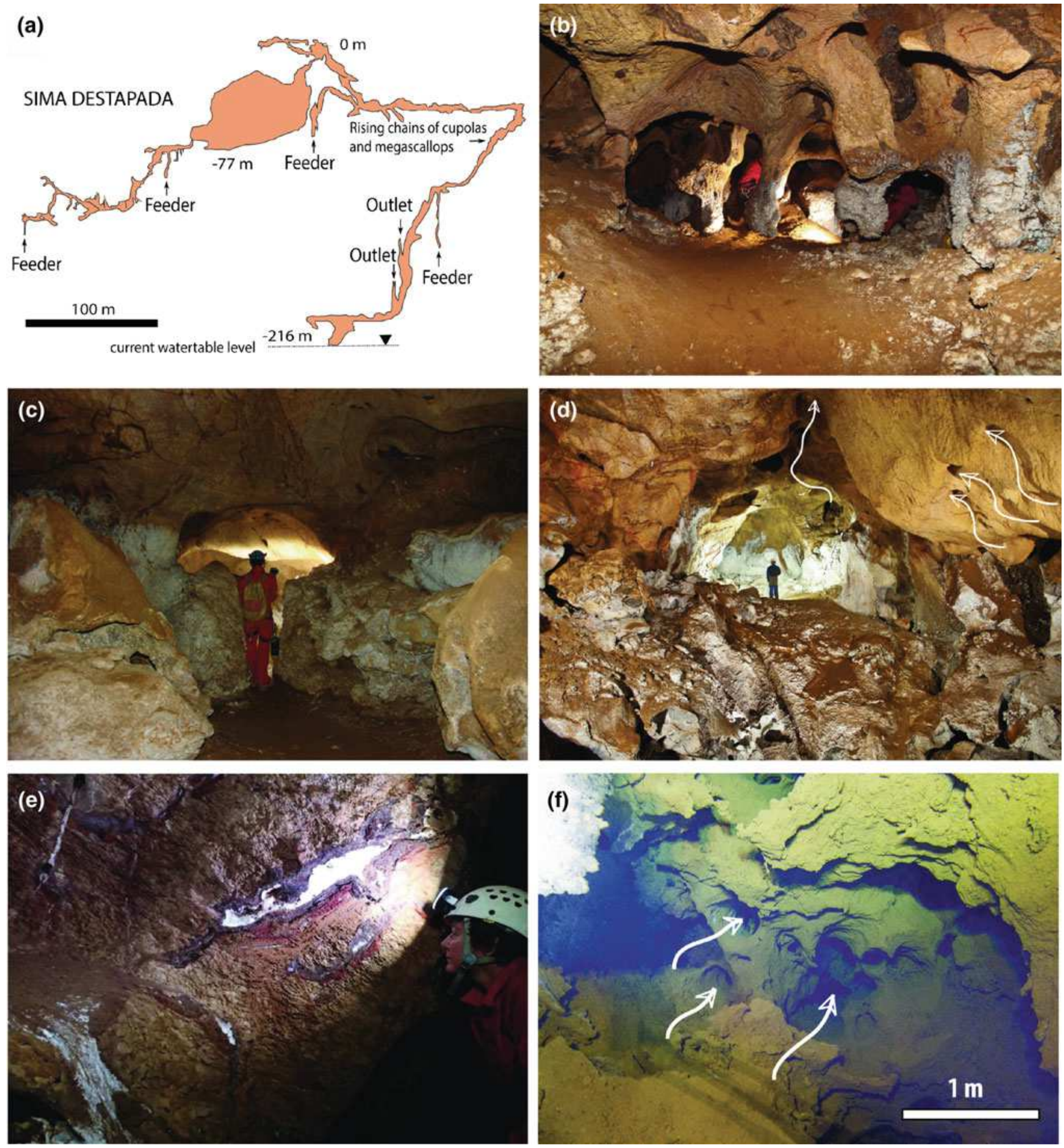


Fig. 5 Evidence for hypogenic speleogenesis in Sima Destapada and Cueva del Agua (Cartagena): **a** topographic profile of Sima Destapada showing feeders and outlets (José Luis Llamusí and others); **b** pendants and partition walls in Sima Destapada; **c** typical passage morphology in Sima Destapada; **d** bubble trails in Sima Destapada; **e** calcite infills in Sima Destapada; **f** subaquatic, probably active, spongework morphologies in the ceiling of Cueva del Agua (Cartagena) (*Photographs* Andrés Ros, José Luis Llamusí and Juan Sánchez)

mechanism, have also been identified in this cavity (Fig. 5b, c), as well as linear half-tube structures with smooth surfaces (ceiling half-tubes) that are evidence of the water flows that dissolved the carbonate bedrock (Fig. 5d). Sometimes, the CO_2 bubbles followed an ascending path, producing bubble's trails (Fig. 5d).

In places, solution pockets and cracks in the carbonate bedrock appear to be filled with calcite spars as a kind of geode. Interestingly, two generations of calcite crystals have been identified: a first rim, usually 10 cm-thick, made of reddish calcite, and a core of whitish calcite (Fig. 5e). These features are a vestige of phreatic, hydrothermal stages, when thermal water dissolved the limestone along planes of weakness in the bedrock. Later, a fall in water temperature favoured calcite precipitation, which occurred in two stages. The oxygen isotopic composition of the reddish calcite ($\delta^{18}O = -10.5‰$, with respect to the V-PDV standard) is 2.3 lower than that of the whitish calcite ($\delta^{18}O = -8.2‰$). Assuming isotopic equilibrium and that the isotopic composition of solution did not change with time, the water temperature may have be decreased by ~15 °C between the first and the second calcite precipitation stage (Gázquez et al. 2016b). Furthermore, the presence of vast deposits of calcite rafts suggests intense CO_2-degassing close to the water table to have occurred in this cavity. In connection with this, other speleothems formed by the sinking of calcite rafts in shallow (~20 cm) pools, such as tower corals, have been observed.

Sima Destapada also accommodates outstanding examples of subaerial aragonite crystallizations in the form of frostwork, which are especially well-exhibited in the Flowers passage. Remarkably, these speleothems cover only one of the passage walls, while the facing wall is coated with calcite crusts and is completely lacking aragonite crystallizations. In the absence of further information, the interpretation might be due to differences in the geochemical composition of the substrate of the two walls (probably higher Mg/Ca favouring the crystallization of aragonite over calcite) or microclimatic differences related to the temperature of the rock and the cave air.

Cueva del Agua runs NW, from the shoreline to Cabezo de Hornos Mountain. Its passages are irregular and the walls show evidence of intense corrosion. This weathering mechanism has produced in situ accumulation of clayey sediments from decalcification of the rock. These muddy layers, tens of centimeters thick, coat the passage walls and ceilings; they detach only due to the turbulence produced by cave divers during surveys. This makes surveying in this cave especially complicated due to resultant loss of visibility. Under natural conditions, there is practically no turbulent water flow and the decalcified detrital materials remain attached to the cave walls in a sort of equilibrium. Evidence for a morphologic suite of rising flow can be found on the cave ceiling, where “swish-cheese” morphologies, bell-shape features and small hemispherical ceiling pockets (some 20 cm in diameter) can be found between the bedrock and the hydrothermal water at the depth of −14 m (Fig. 5f).

In recent times, other smaller caves with signs of hypogenic/hydrothermal processes have been found in this area, including Cueva de la Plata and Cueva del Gigante. The former is located barely 1100 m from the entrance of Sima Destapada; it exhibits splendid examples of cave clouds and cave cones (Fig. 7). Cueva del Gigante is 10 km east of Sima Destapada-Cueva del Agua System. Its ceilings display examples of boxwork, ferromanganese coatings and condensation cupolas.

3.3 Caves of the North-Western Sector

Cueva del Puerto is located in the NW of the Murcia Region in the Sierra del Puerto Mountain Range, near the town of Calasparra. The cave is developed in limestones and dolostones of the Upper Cretaceous, belonging to the external Prebetic domain; these materials are overlain by marls of Miocene age that served as the impervious confining cap to the aquifer.

Cueva del Puerto was discovered in the early 1970s by the GECA-OJE speleological team; its two entrances lie at 503 and 495 m a.s.l. and its karstic network extends over 4300 m, forming the second largest known cave in the Murcia Region, after Sima de la Higuera (Cuatro Pico Club and Pliego Espuña Club 2001). The cave morphology is determined by two faults running NW-SE that are 250 m apart (Fig. 2). It exhibits clear spongework and maze morphologies. The hydrothermal flow into the system occurred through a 100-m-long fault, which served as water feeder to the system in the past. Transitional features connect passages and chambers at different depths. Several 100 m-deep subvertical fractures connect the Gran Diaclasa Chamber (~ −80 m) with the shallower Bloques Chamber (~−40 m) (Fig. 2). This master passage runs W-E and its walls and ceiling exhibit examples of hypogene morphologies including rising chains of cupolas, partition walls and bubble trails (Fig. 6). Frequently, the accumulation of air bubbles on the cave ceiling under phreatic conditions generated solution pockets and corrosion cupola, usually attributed to a condensation-corrosion mechanism resulting from the high content of CO_2 from water degassing (Cigna and Forti, 1986; Plan et al. 2012). On occasions, boxwork formations have been identified on the surface of cupolas (Fig. 6b).

Cueva del Puerto shows several examples of speleothems related to hydrothermal waters. This includes calcite spars in cracks in the bedrock and deposits of calcite rafts. These two types of speleothems represent two different stages of the cave’s development. The calcite spars formed under subaqueous conditions. In contrast, calcite rafts precipitated on the water surface, which indicates that the water table intercepted the cave level at some point. The absence of other speleothems usually formed close to the water surface (e.g., cave clouds, raft cones and folia) indicate that the fall in water level was probably relatively abrupt. In addition to carbonate speleothems, gypsum is present in Cueva del Puerto, which

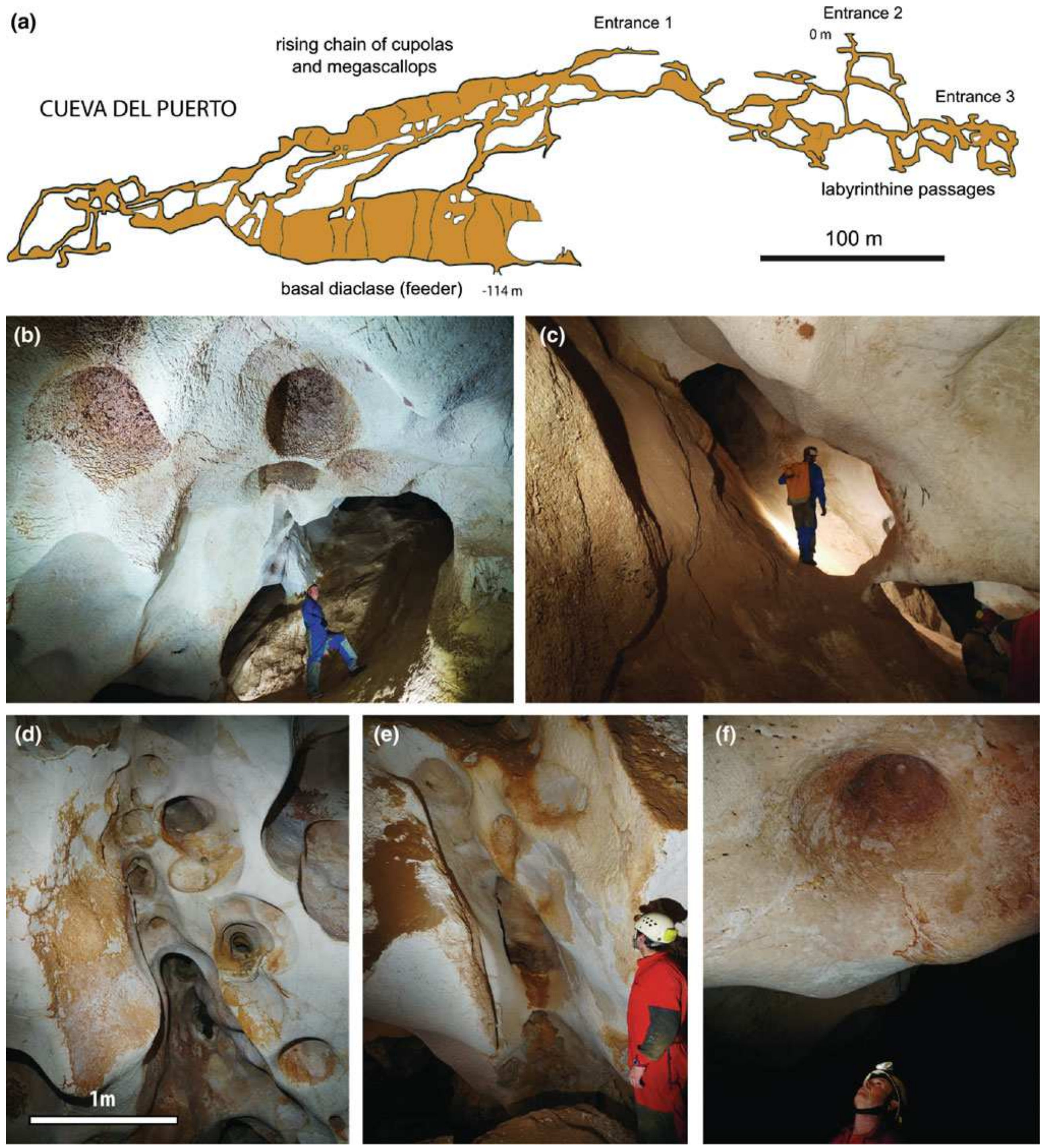
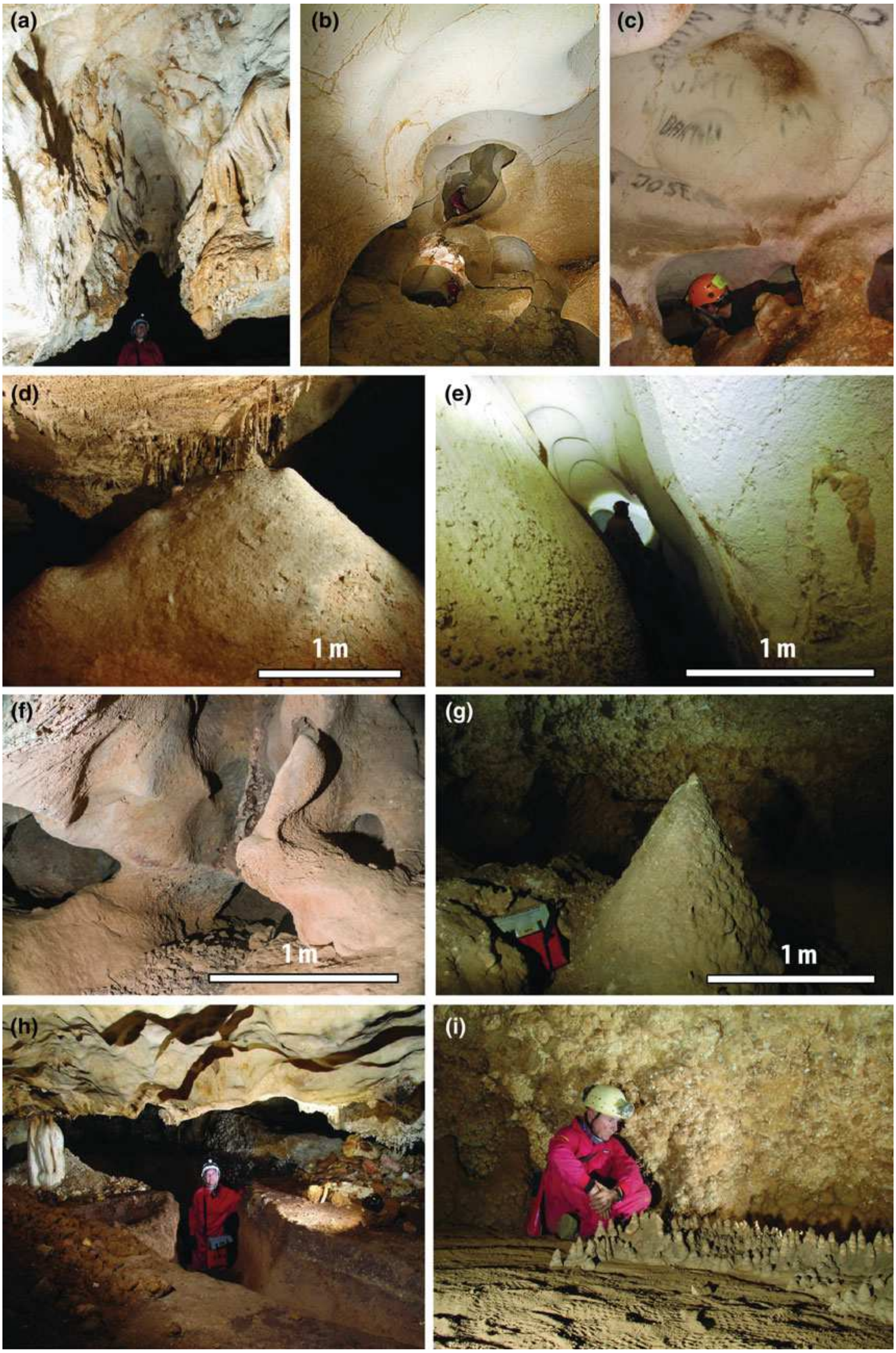


Fig. 6 Evidence for hypogenic speleogenesis in Cueva del Puerto (Calasparra): **a** topographic profile showing the maze cave network (Cuatro Picos Speleoclub); **b** cupolas and boxwork; **c** partitions; **d** cupolas; **e** rising channels; **f** cupola (*Photographs* Andrés Ros and José Luis Llamusí)

Fig. 7 Evidence for hypogenic speleogenesis in other caves of the Murcia Region. **a** Ceiling half-tubes in Sima del Almez (*Photograph* Andrés Ros and José Luis Llamusí); **b** slow phreatic dissolution features in Cueva de Luchena (*Photograph* A. González-Ramón); **c** cupolas and partition walls in Sima de la Almagra (*Photograph* Andrés Ros and José Luis Llamusí); **d** pile of calcite rafts in Sima del Pulpo (*Photograph* Andrés Ros and José Luis Llamusí); **e** rising chains of cupolas in Cueva de Luchena. (*Photograph* A. González-Ramón); ▶ **f** phreatic dissolutional forms in Cueva del Agua-Lorca (*Photograph* Andrés Ros and José Luis Llamusí); **g** cave cones in Cueva de la Plata (*Photograph* Andrés Ros and José Luis Llamusí); **h** solutional pockets and megascallops in Sima del Almez; **i** tower coral in Cueva de la Plata (note that this are note exclusive of hypogenic caves) (*Photograph* Andrés Ros and José Luis Llamusí)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appears in the form of crusts and gypsum flowers. The origin of sulfates in this cave is unknown to date, but is probably linked to sulfuric acid speleogenesis (SAS) as described for many other caves worldwide (e.g., Palmer and Palmer 2012; Audra et al. 2015; De Waele et al. 2016).

In the setting of Cueva del Puerto, there are other smaller caves where evidence for hypogenic processes has been observed. For instance, Sima del Pulpo (Cieza) also accommodates examples of gypsum speleothems, such as the one named 'the white octopus' (Grupo Atalaya 1997). This indicates that its origin was probably also related to the same events of SAS that generated Cueva del Puerto. Indeed, examples of folia, cupolas and ceiling dissolution pockets can be found in this cavity, suggesting their hypogenic origin. Also, Sima de Benis (Cieza) (Pérez-López et al. 2009) hosts splendid examples of folia, cave clouds and phreatic dissolution forms (Fig. 7), as well as some gypsum speleothems. Finally, in Cueva del Pozo (Jumilla) there is evidence of a morphologic suite of rising flow (Federacion Espeleologica de la Region de Murcia 1995).

3.4 Other Hypogenic Caves in the Murcia Region

In addition to the caves in the three areas described above, there are other karstic systems in the Murcia Region that show clear evidence of hypogenic processes. For example, in Cueva del Agua of Lorca, in the Talayón mountain range (Lorca), the recent lowering of the water table has allowed access to several vertical shafts that acted as feeders in the past. The air temperature in this cave oscillates around 21 °C. It accommodates spectacular examples of euhedral calcite spars and boxwork, bubble trails, rising chains of cupolas and partitions, among other hypogenic feature (Gázquez et al. 2016a).

Cueva de Luchena, in the Pericay mountain range, exhibits rising chains of cupolas, feeders and outlets, partitions and cupolas (Fig. 7). However, speleothems typically related to hydrothermal waters have not been found in this cavity. This has been interpreted to mean that the water table did not lie close to the cave level for a long time and that the water level fall that emerged the cave was relatively rapid (González-Ramón et al. 2014).

Sima del Vapor (Alhama de Murcia) is a 85 m-deep vertical cave located on the hill of Castillo, near the town of Alhama de Murcia. Air temperatures vary and increase with depth, ranging from 27 to 43 °C. The carbon dioxide concentration in the cave atmosphere is relatively high (1.8%), whereas the oxygen content is around 18.5% (Asencio and Aboal 2011). Given such extreme environmental conditions, topographic surveys and research have been extremely complex. Nevertheless, this cavern has been a site for the study of the role of cyanobacteria on acetylene reduction and nitrogen fixation in extreme environments (Asencio and Aboal 2011).

Finally, Cueva de la Almagra is located near the thermal baths of the town of Fortuna. This cave displays clear evidence of a hypogenic origin, including labyrinthine passages (maze cave pattern), examples of cupolas and partitions (Fig. 7). The current cave air temperature is around 28 °C, suggesting relatively recent hydrothermal processes.

4 Conclusions

Signs of hypogenic mechanisms have been detected in fourteen caves in the Murcia Region so far. CO_2-based hydrothermal processes are proposed for the formation of Sima de la Higuera, Sima Destapada, Cueva del Agua-Cartagena, Cueva de la Plata, Cueva del Gigante, Sima de Benis, Cueva de Luchena, Cueva del Pozo, Sima del Alméz, Cueva del Agua-Lorca, Sima del Vapor and Cueva de la Almagra. In contrast, Cueva del Puerto and Sima del Pulpo, where massive deposits of gypsum have been identified, were probably generated by SAS mechanisms. The wide range of hypogenic speleogenesis indicators and hydrothermal speleothems reveal that the hydrothermal field of the Murcia Region hosts one of the densest active hypogenic subterranean networks in the world. Surveys of this karstic network are still in progress, and so important discoveries in the Murcia Region caves are possible in the coming years.

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