MORPHOLOGICAL LINKS BETWEEN DISTINCT CAVE SYSTEMS, AS REVEALED BY THE MAGNETIC PROPERTIES OF CAVE SEDIMENTS

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SUMMARY

Allogenic clastic sediments are often preserved within cave systems. These sediments can retain, within their magnetic record, details of their depositional and other palaeoenvironments.

During the evolution of a karstic landscape cave systems can be dissected, leaving isolated fragments of the original systems. The sediment record retained in the caves isolated in this way may indicate some characteristics of the original cave systems.

These two observations form the basis of this study. The sediments from physically distinct cave systems are compared to provide evidence of past connections.

Sediment cores were collected from nine sites in the Matienzo region of northern Spain. The magnetic susceptibility profiles of the cores were measured, in a laboratory at the University of Lancaster, and then compared. From these measurements four groups of caves are identified according to the range of the susceptibility values from their sediments.

INTRODUCTION

Caves act as effective repositories for clastic sediments. This sediment record can hold significant palaeoenvironmental information. This study aims to utilise such information in order to assist further understanding of the development of a particular karst landscape.

The development of a karst terrain is dependent on two main criteria:

1. The presence of a rock that is highly soluble and with well developed secondary porosity.
2. The presence of a solvent to exploit the properties of such a rock.

In addition to these two criteria the best potential karst rocks have low primary porosity thus enabling the concentration of solvents into the fissures and cracks causing the secondary porosity. If cave features are to develop and be maintained a high mechanical rock strength is also desirable. The most common karst rocks are limestones followed by other carbonate rocks, evaporites, silica-cemented quartzites, and siliceous sandstones.

Precipitation within the hydrological cycle forms the basis of the solvents that chemically denude karst rocks. Pure water is relatively ineffective in dissolving carbonates, but once it is combined with carbon dioxide or organic acids stored in the biomass it can become a potent chemical agent.

Present-day distinct cave systems may have been connected in the past. The evolution of the surface karst may have bisected cave passages, and so have isolated sections of cave systems from each other. If the evolution of the landscape progresses in a purely karstic manner, with the absence of surface erosion processes such as glaciation, it should be possible to link the development of surface and subterranean features. A potential method for establishing morphological links between now isolated caves is comparison of sediment stratigraphies from sample cave sites. If the same underground river is the morphogenic agent for development of two caves, similar sediment stratigraphies should be present in both sites.

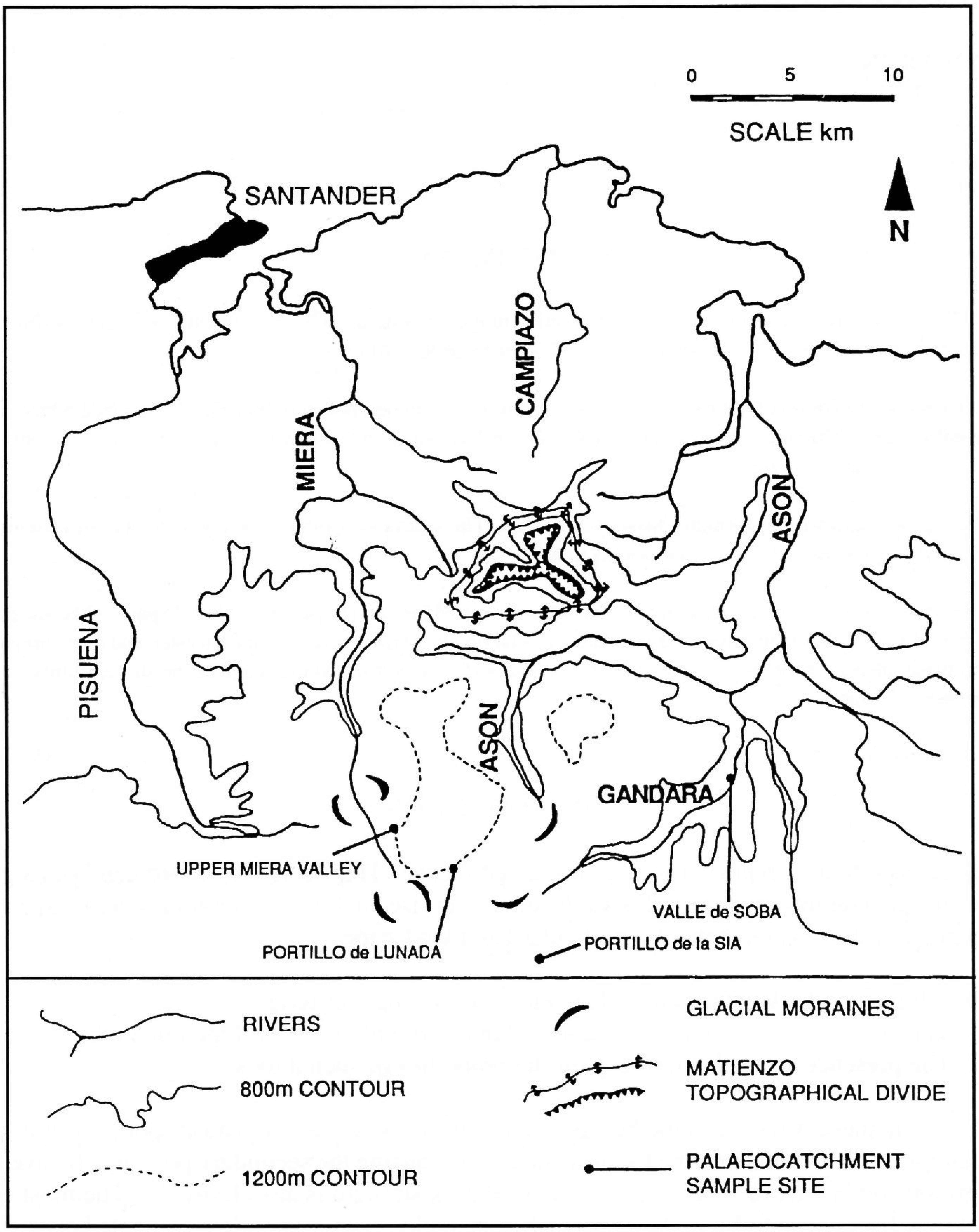

Fig. 1. The Matienzo region.

The area chosen for this study is the Matienzo region of Cantabria, northern Spain (Fig. 1). Matienzo presents a well developed karst landscape with an estimated minimum of 1.8 million years of uninterrupted karstic development (Waltham 1981). Numerous and extensive cave systems are found there.

In pursuit of the aim to compare sediment stratigraphies, sample sites were identified and sediment cores collected. These cores were later analysed to give magnetic susceptibility values, and the results were compared between the sites. Attempts were also made to identify potential palaeocatchments for the rivers which formed the caves of Matienzo.

The magnetic susceptibility properties of sediment cores were chosen for analysis due to their ability to highlight changes in conditions within the source area of sediments. Alterations in catchment characteristics will be reflected in the corresponding sediments deposited within the fluvial system. Dearing, Elner & Happey-Wood (1981), working in the Welsh uplands, linked high magnetic susceptibility values in lake sediment cores with periods of bank erosion within the lake-catchment. These findings are further explained by Dearing et al. (1985) who by using magnetic susceptibility values demonstrated the ferrimagnetic mineral depletion down soil profiles. It follows that sediments derived from material with high ferrimagnetic mineral content, such as topsoil, can be detected in the depositional zone by magnetic susceptibility measurement.

CAVE SEDIMENTS AND THEIR MAGNETIC PROPERTIES

The study of cave sediments has been an important research focus for some years. Ford & Williams (1969) point to the archaeological and palaeo-environmental significance of cave sediments to explain this. Bull (1977) highlights the isolation of cave sediments, within a cave environment, in his assessment of their usefulness in determining palaeoclimatic conditions. The relatively stable cave environment protects sediments from normal weathering processes.

Cave sediments can be either autogenic, i.e. derived from within a cave environment, or allogenic, having a source outside the cave. In reconstructing palaeoenvironmental conditions, allogenic and in particular fluvio-clastic sediments are of greatest importance.

The key to palaeoenvironmental reconstruction using the magnetic properties of cave sediments is the phenomenon known as **depositional remanent magnetism**. Fine sediment particles, upon settling, preferentially orientate themselves according to the earth's magnetic field. Variations in the Earth's magnetic field over time are reflected in changes in the alignment of the sediment particles found through a sediment profile. Therefore, if the same pattern of palaeomagnetic variations is found in the profiles of two separate cave deposits, it may be inferred that the deposits are of the same age. However, there are several complicating factors.

Watkins (1971) showed how potentially-flawed early work in this field is often cited to prove later unexpected findings. This problem is highlighted in the so-called "red bed controversy". Independent evidence has shown that over periods of millions of years complete polarity switches of the earth's magnetic field have occurred. The magnitude of remanent magnetism contained within red sediments and the abundance of these sediments worldwide led to many early palaeomagnetic studies being undertaken. The essence of the argument concerns the source of the remanent magnetism that is being measured. Was it acquired at the time of deposition ('depositional remanent magnetism') or was it acquired after deposition due to some chemical reaction that proceeds at an unknown rate ('secondary chemical remanent magnetism')? Compounding the problem are the fine-grained haematite crystals which are responsible for the colour of red beds, and which undoubtedly impart secondary chemical remanent magnetism to them. The small size of these crystals leads to instability of the magnetization over long periods of time. An interesting overview of this debate is provided by Butler (1992).

However, the debate is entirely concerned with long-term chronologies based on the correlation of geomagnetic polarity reversals. Chronologies described using secular variations within and between the major periods of polarity reversals have been better received. The pioneering work of Mackereth (1971) decribed a chronology of secular magnetic variations calibrated against radiocarbon dating techniques for a sediment core from the bed of Lake Windermere. Oldfield & Richardson (1990) cite observatory records, archaeomagnetic records, models of geomagnetic field changes, pollen analysis and comparison with other secular variation chronologies amongst a host of corroborative tools used for secular magnetic variation studies.

Magnetic susceptibility is defined as the degree to which a sediment sample can be magnetized by a fixed, known outside magnetic field. This is operationalized as the ratio between the intensity of magnetization produced in a sample to the intensity of the magnetic field that produces the magnetization.

The calibre of clastic sediments deposited within caves varies from large bedload boulders and gravels to fine suspended load silts and clays. The presence of fine-grained clays is often much in evidence due to the commonest clastic weathering products of the source karst rocks being of that calibre.

In cave passages of phreatic origin and vadose caves that experience periodic flooding, suspended sediments are often deposited on all surfaces within a cave, including the roof. Typically however the floor is subject to the greatest deposition rates. Due to the complexity of cave systems, often comprising a maze of passages with changing cross-sections and surface roughness, deposition rates frequently vary considerably within a single cave.

Repeated flooding can remove any pre-existing deposits from main cave passages, replacing them with deposits contemporary with the flood event. Side passages and sheltered areas of caves can however build up suites of sediments due to the low energy environments which exist there. These sites can provide the most extensive sedimentary record within a cave environment. Cave passages that are abandoned as a through route for cave water can also provide conditions in which good sedimentary records can be found.

Having highlighted the usefulness and versatility of cave sediment studies, it must also be emphasised that care must be taken in their interpretation. For example, caves located in glaciated areas commonly contain varved clays within their suites of deposits. Reworking of sediments by cryoturbation can also be a significant feature in these areas, making interpretation more difficult. As Jennings (1985) warned,

"These deposits possess tremendous variety, both lithological and genetically; their inheritance of characteristics acquired outside the cave environment and their liability to especially complex stratigraphy make for difficulties in their study, including their classification".

This point is particularly relevant to clastic deposits due to the occurrence of both autogenic and allogenic sediments within them.

THE FIELD AREA

The Matienzo area of northern Spain was chosen for this study because it has caves containing relatively undisturbed allogenic clastic sediments, which are easy to get to. Also, the author had prior personal knowledge of them, and logistic backup for visiting the caves and collecting samples safely. Apparently rapid downward changes in the level of the phreatic surface have left relict cave passages in the area.

The main karstic feature of the Matienzo area is the large enclosed depression that bears the name of the region. The area contained within the topographical divide of the depression is 26.3 km^3 of which about 3 km^3 consists of a nearly flat 'Y" shaped valley floor (Fig. 2).

The northern arm, La Secada, contains the hydrological outlet to the depression, Cueva de Carcavueso (alt. 145 m). The col leading out of this end of the depression is at an altitude of 450 m.

The arm to the southeast, Ozano, contains a small tributary stream that joins the main Matienzo river before it enters Cueva de Carcavueso. The col at the head of the Ozano arm of the depression, at an altitude of 364 m, is the lowest point on the topographical divide of the depression.

La Vega arm, to the east, contains Cueva del Comellante which is the resurgence cave for the main Matienzo river. The river connects La Vega and La Secada via a cave, Cueva del Agua. The exit col of this arm of the depression is at an altitude of 678 m.

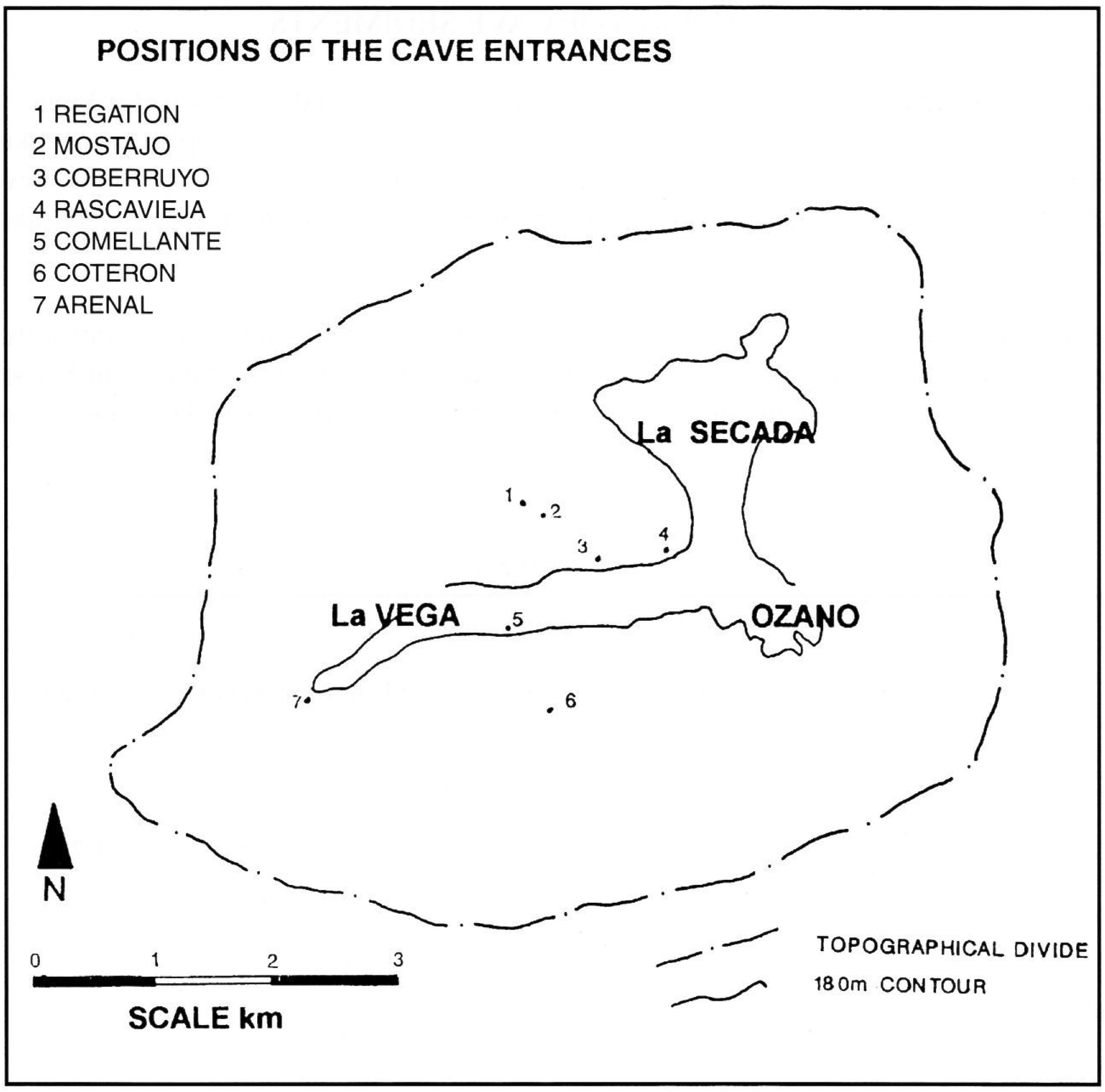

Fig. 2. The Matienzo depression, with positions of entrances to the caves discussed in the text.

Alluvium covers the flat areas of all three arms. The axis of a regional anticline runs roughly along the line of La Vega arm, which is the best known arm in speleological terms. In view of this and the need to limit the geographical extent of the study, La Vega was chosen as the area for investigation.

Geology

Other than unconsolidated valley floor alluvial deposits the entire area is formed of rocks laid down in the Lower Cretaceous (Mills & Waltham 1981). The greatest area is floored in limestones, occasionally with thin sandstone beds and lenses. The limestones are up to 600 m thick, and are divided into 300 m of thin-bedded Albian rocks, 100 m of massive Urgonian Limestone and 200 m of thin-bedded Aptian rocks. Underlying the limestones and forming a boundary to karstic development are impervious Barremian sandstones and marls. These underlying beds outcrop sporadically in the Vega and Ozano arms of the depression. The geological sequence is summarized in Table 1.

TABLE 1

GEOLOGICAL SEQUENCE IN THE MATIENZO AREA
(adapted from Mills & Waltham 1981)

age	*thickness*	*description*
Albian	300 m	Thin bedded limestones, with some massive beds
Aptian	100 m	Massive bedded Urgonian limestone, with thin marls
Aptian	200 m	Thin bedded limestones with *Orbitalina,* also thin sandstones
Barremian	500 m	Sandstones and marls

SAMPLING OF CAVE SEDIMENTS

The caves investigated are a representative sample of the available sites in La Vega. Sites chosen were from the northern, southern and western sections of the valley. Samples were taken from both present-day active caves, and relict cave passages. Several of the caves selected have development on several levels; in these cases, with the exception of the South Vega system, cores were taken from each major level.

In determining suitable sediment banks for sampling, sites were chosen where there were no probable autogenic input sources nearby, where there was no anthropogenic disturbance, and where the banks consisted of fine-grained sediments of a form indicating fluvial deposition. The caves chosen are listed in Table 2.

TABLE 2

CHARACTERISTICS OF THE MAGNETIC SUSCEPTIBILITY SAMPLES

cave	entrance altitude (m)	cave length (m)	core length (cm)	max *k*	min *k*	range
Torca del Coteron	370	21475	49	1.8	0.5	1.3
Cueva del Comellante	170	450	41	8.0	1.7	6.3
Cueva de Arenal	220	200	35	11.2	0.6	10.6
Torca Regaton	303	3247	{1A 83.5, 1B 53}	41.2	1.2	40.0
Torca del Mostajo	312	6582	1A 36	1.5	0.7	0.8
			{2A 88, 2B 66}	1.1	0.4	0.7
			3A 64.5	1.6	1.2	0.4
Cueva de Coberruyo	300	150	54.5	3.9	1.1	2.8
Cueva de Rascavieja	300	450	29	3.3	1.6	1.7

Torca del Coteron (no. 6 in Fig. 2) is the middle entrance (in terms of altitude) of the South Vega System. The combined lengths of the major constituent caves of this system (Torca del Azpilicueta, Torca del Coteron, Cueva de la Renada) make it the longest in the area. The two main passage developments in Coteron are centred around the 230 m and 200 m altitudes. The character of the cave is almost entirely of a relict phreatic nature containing substantial quantities of sediment. Access to these levels is via two pitches of 45 m and 13 m depth. The sample site (see Fig. 3) was in the vicinity of "The Edge of the World", found on the 230 m level. Two-and-a-half hours' caving is required to reach this point.

Cueva del Comellante (no. 5 in Fig. 2) is the resurgence for water found in the lower levels of the South Vega System. Water sinking within Cueva de la Renada has been dye traced to a point in Comellante. Typical discharges of around 0.5 cumecs have been recorded. The short, horizontal nature of this cave makes access relatively easy. Normal progress is halted where the cave roof descends to meet the water level at a sump. The sample site (see Fig. 4) is 30 m before the sump and 5 m above that level. The source of this water, beyond the lower levels of the South Vega System, is at present unknown.

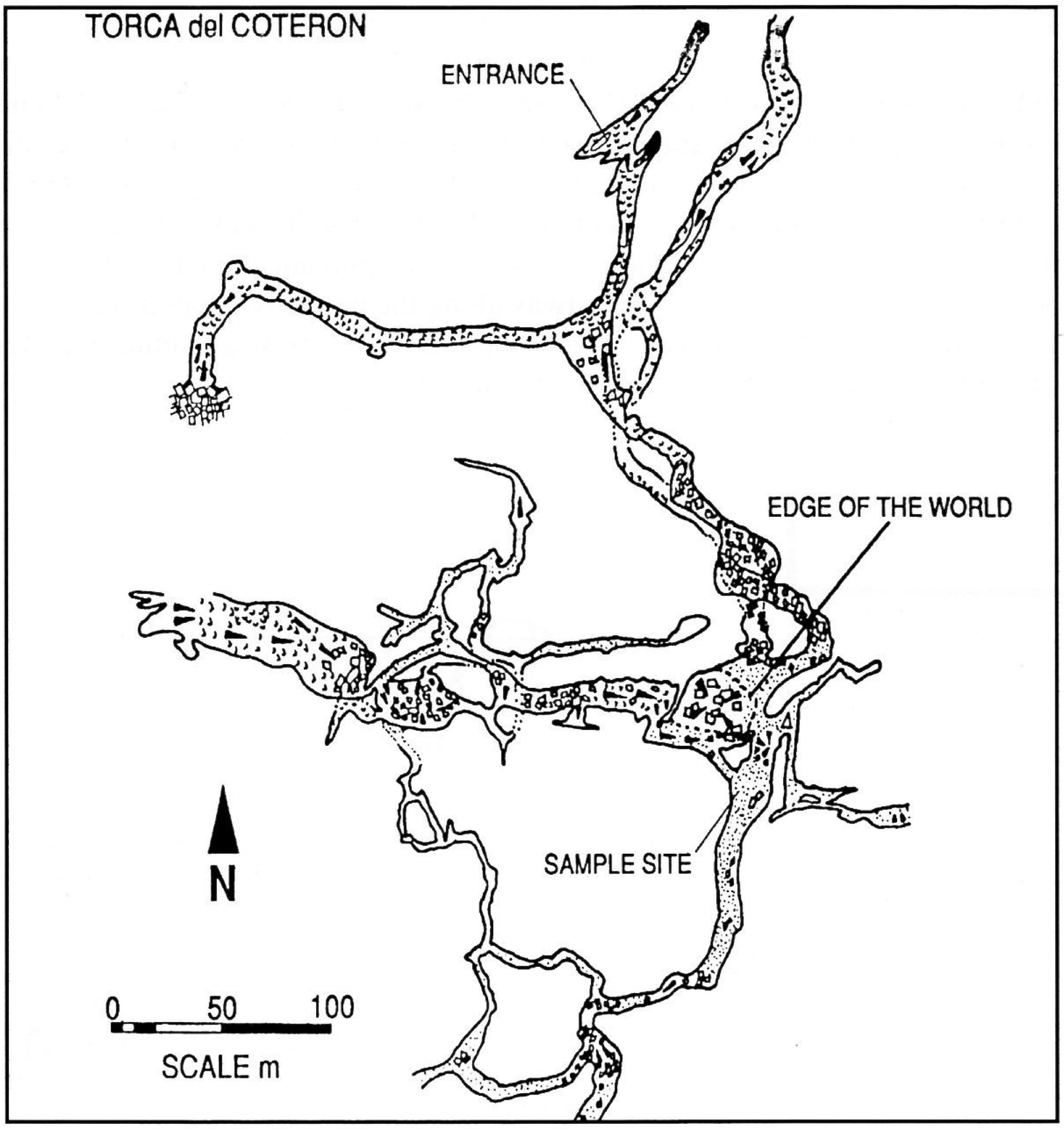

Fig. 3. Position of the sampling site in Torca del Coteron (after an original by P. Smith).

Cueva del Arenal (no.7 in Fig. 2), at the head of La Vega, has three entrances 20 m above the valley bottom and the permanent spring level. At times water emerges from its main entrance. A very strong cold draught emerging from the cave suggests that considerable dry extensions exist which have not yet been discovered. The sample site for Arenal (see Fig. 5) is just beyond the entrance zone of the cave.

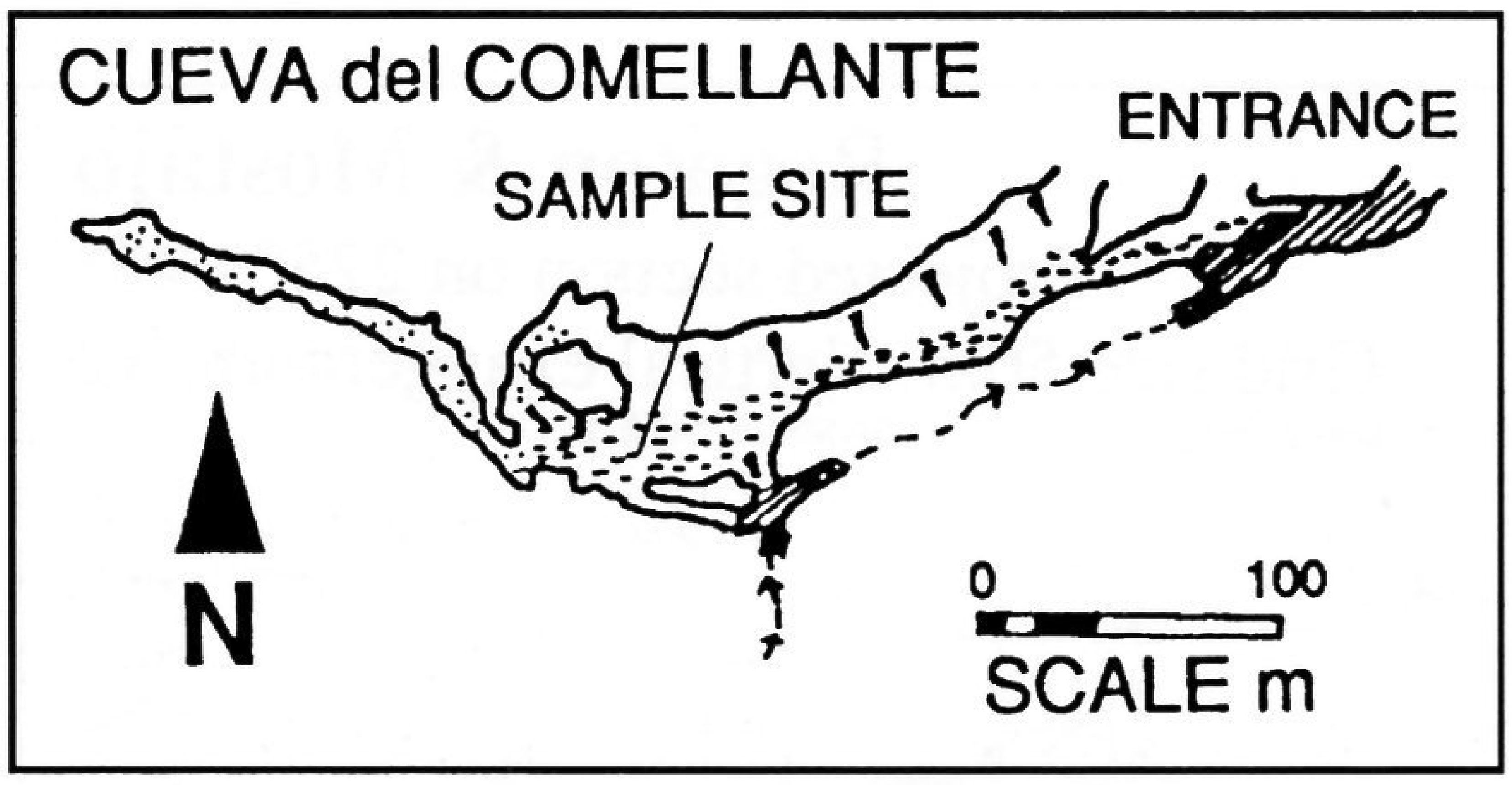

Fig. 4. Position of the sampling site in Cueva del Comellante (after an original by P. Smith)

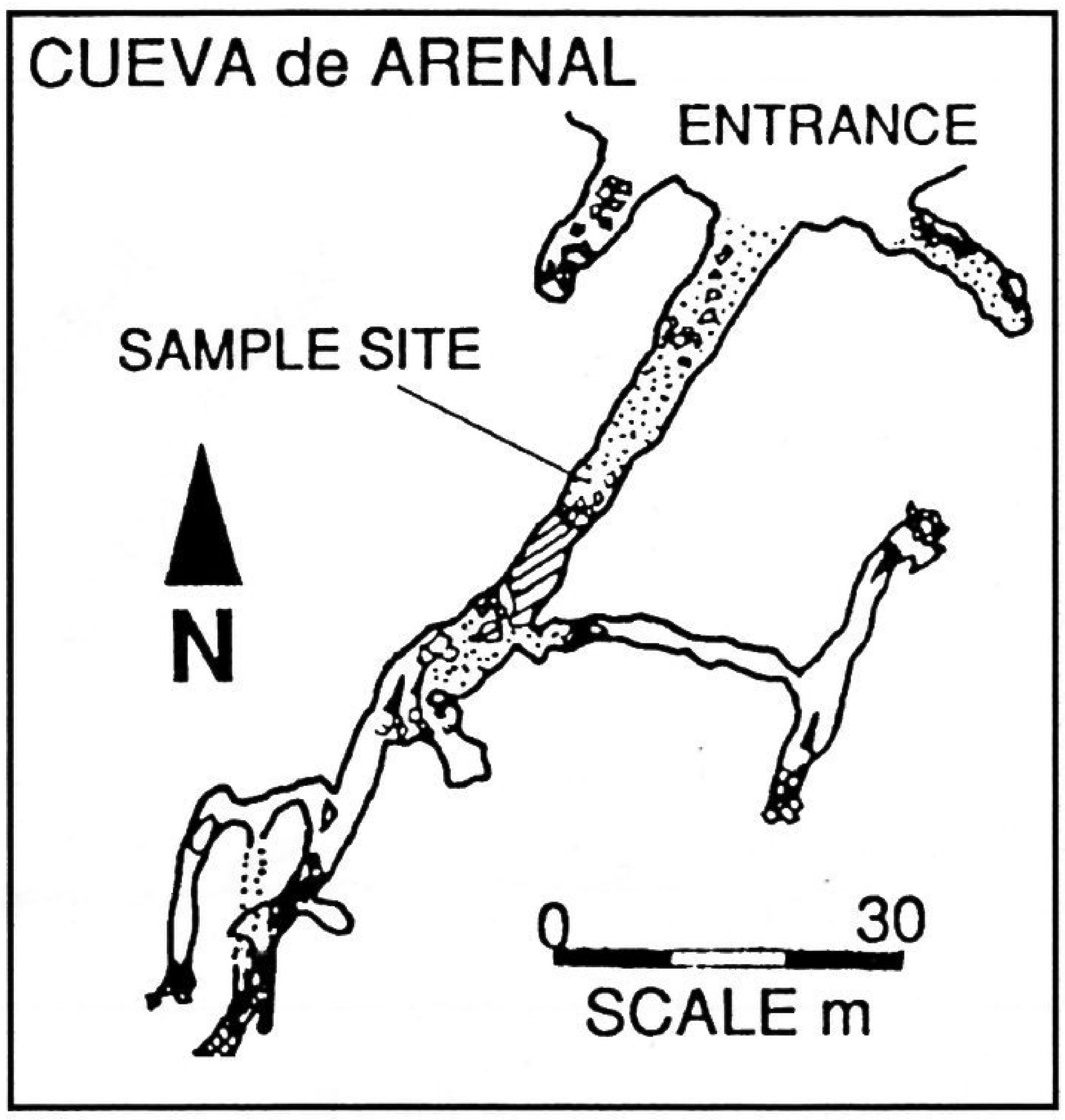

Fig. 5. Position of the sampling site in Cueva de Arenal (after an original by P. Smith).

Torca Regaton (no. 1 in Fig. 2) is found on the north slopes of La Vega, and was discovered in 1992. The entrance series drops subvertically for 130 m. The largest single drop of nearly 70 m necessitates the use of specialist single rope techniques and equipment to enter the lower reaches of the cave. Other than the entrance drops of the cave, the entire known passage development is at this lower level. The altitude of this development (c. 180 m) corresponds with the present-day valley floor level. The lower passages are of two types, active vadose streamways and larger abandoned phreatic tunnels with occasional windows down to the phreatic zone. The sample site is midway along the main abandoned section of the cave (see Figs 6 & 7). The discovery of this cave gave a rare opportunity to study a feature untouched by human influences, as the author was only the third person to enter this cave.

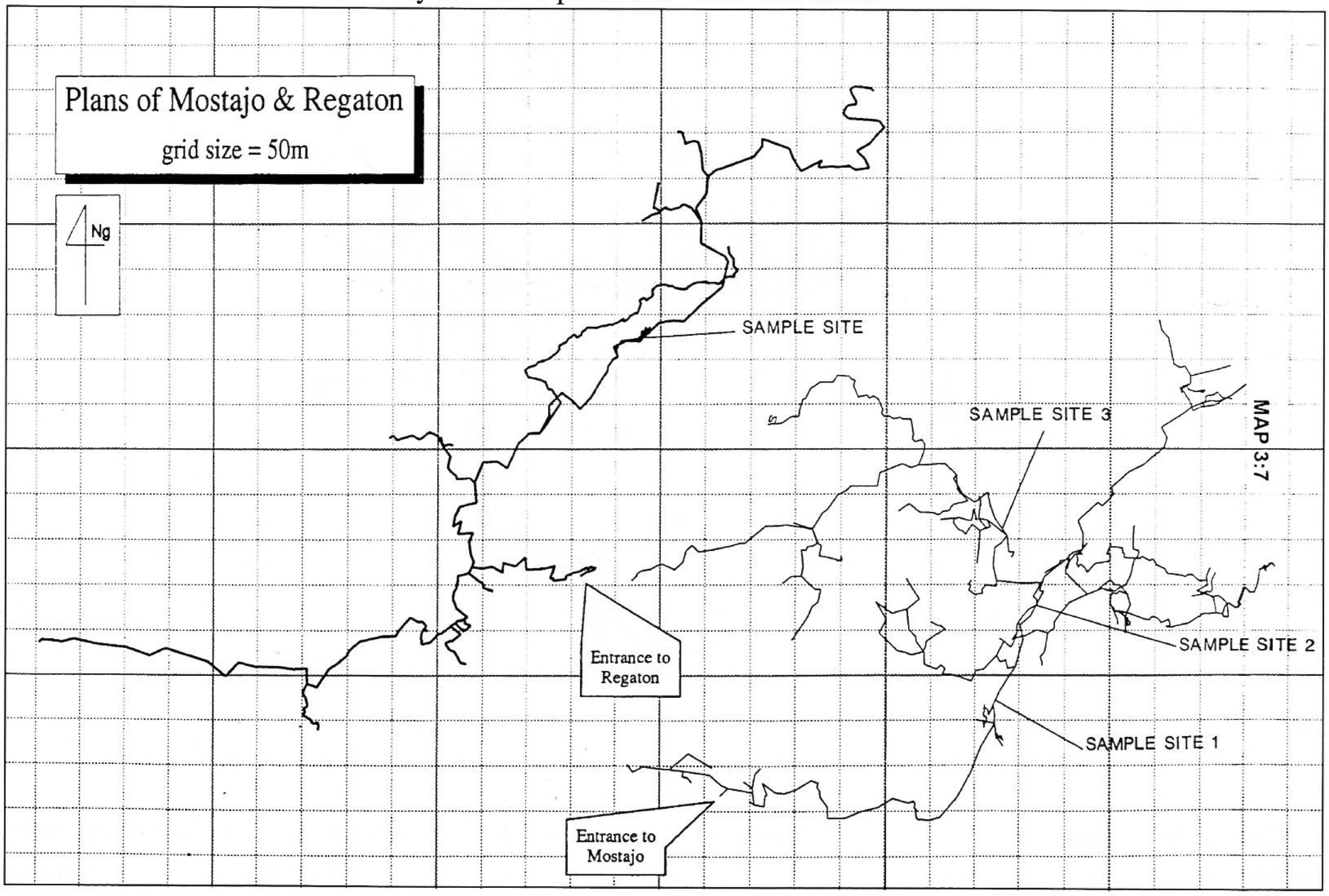

Fig. 6. Positions of the sampling sites in Torca Regaton and Torca del Mostajo.

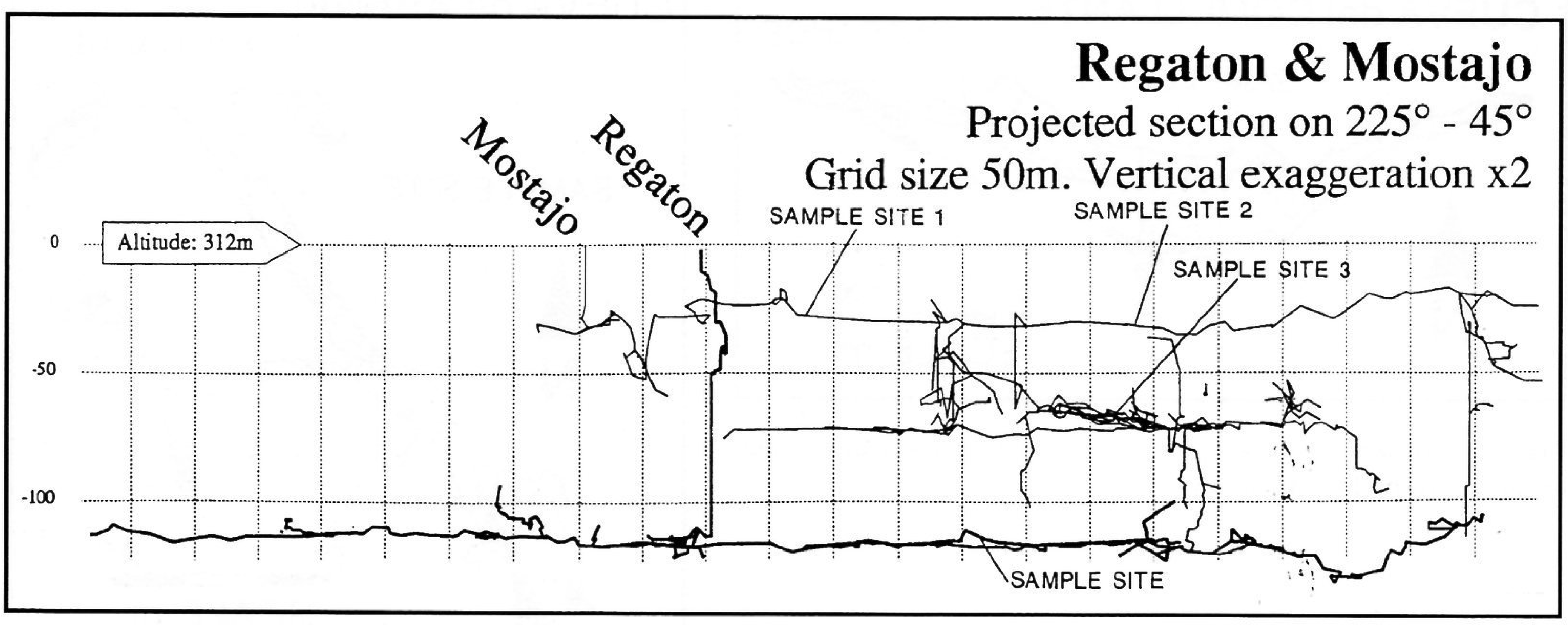

Fig. 7. Cross-section through Torca Regaton and Torca del Mostajo, showing the positions of the sampling sites.

Torca del Mostajo (no. 2 in Fig. 2) is an extensive cave on the northern side of La Vega. Two distinct levels of relict phreatic development are evident. Entry to the upper level at an altitude of 280 m is via an entrance drop of 22 m. This large, dry tunnel contains many deposits, both clastic and calcite precipitates. A further vertical drop of 30 m from the upper gallery accesses the 240 m-level extensions. Unlike the upper passages, development at this level does not follow a linear pattern; the confusing number of passage directions can lead to route-finding problems. The complex passage orientation is highlighted in the survey of the cave. Deposits are abundant and the passages are clearly phreatic in origin. Specialist caving knowledge and equipment are needed to enter this system. Three sampling sites were located in Mostajo (see Figs. 6 & 7). The first site is 200 m along the upper level. A potential problem of calcite intrusions into the clastic sediments at this site led to the taking of another sample at this level, another 230 m along. A site 300 m from the entrance to the lower extensions was chosen for sampling from the 240 m level.

The close vicinity of Regaton and Mostajo led to the expectation that they would contain similar sediments.

The two final cave sites have their entrances at the base of a high cliff formed in Urgonian limestone, at the northern edge of the valley.

Cueva de Coberruyo (no. 3 in Fig. 2) appears to be a short segment of a fossil phreatic cave running parallel to the edge of the valley. The entrance may have formed when the valley developing laterally breached the cave passage. The sampling site (see Fig. 8) is 46 m along the eastward-heading branch of the cave.

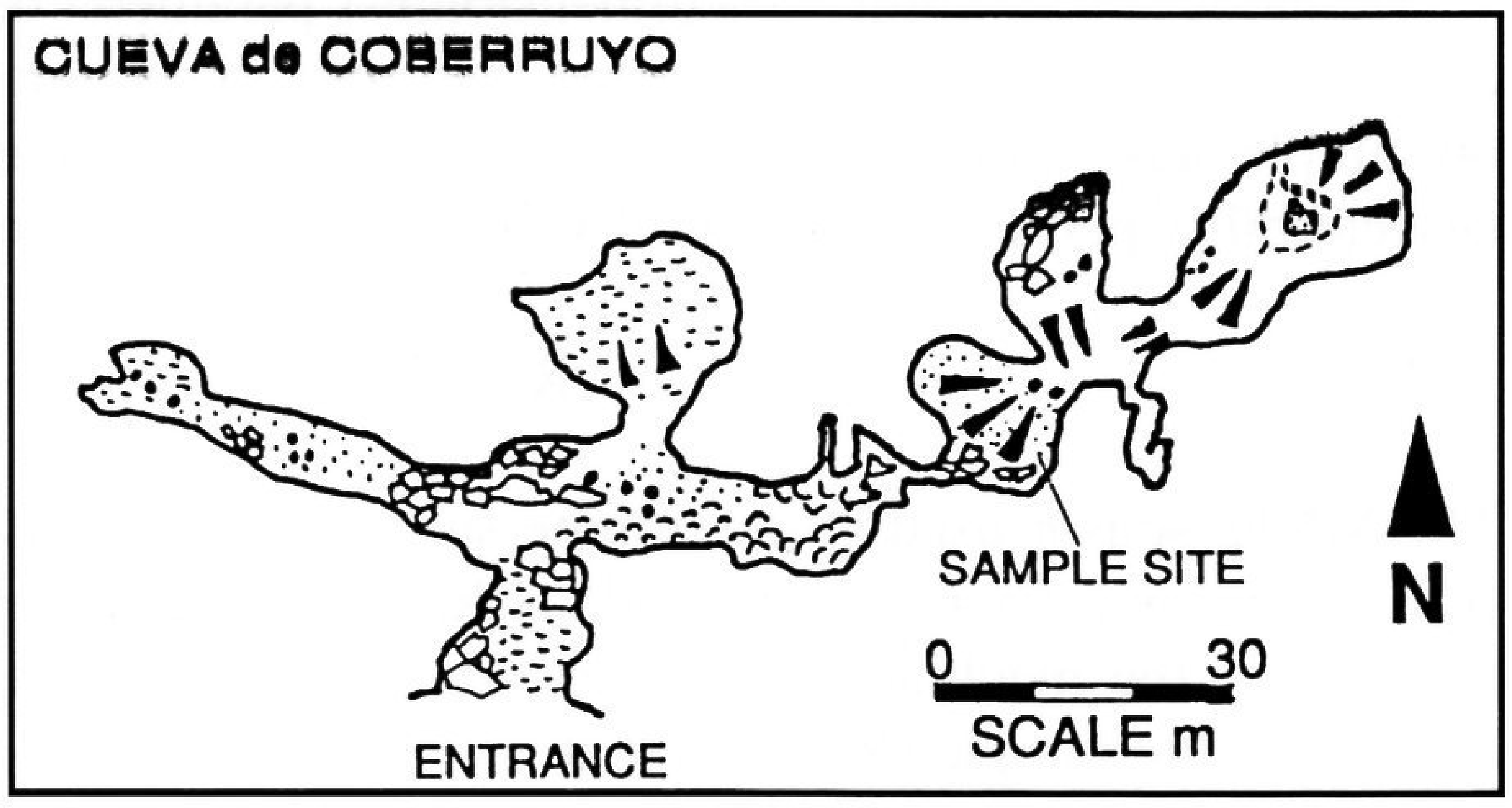

Fig. 8. Position of the sampling site in Cueva de Coberruyo (after an original by P. Smith).

Cueva de Rascavieja (no. 4 in Fig. 2) consists of a steeply descending slope 50 m long, leading to a passage 30 m wide. The cave heads directly into the hillside and is blocked by a large boulder fall. The sample site (see Fig. 9) is in an alcove 60 m along the eastern wall of the passage, away from the influence of surface debris and any autogenic breakdown products which may have travelled down the entrance slope.

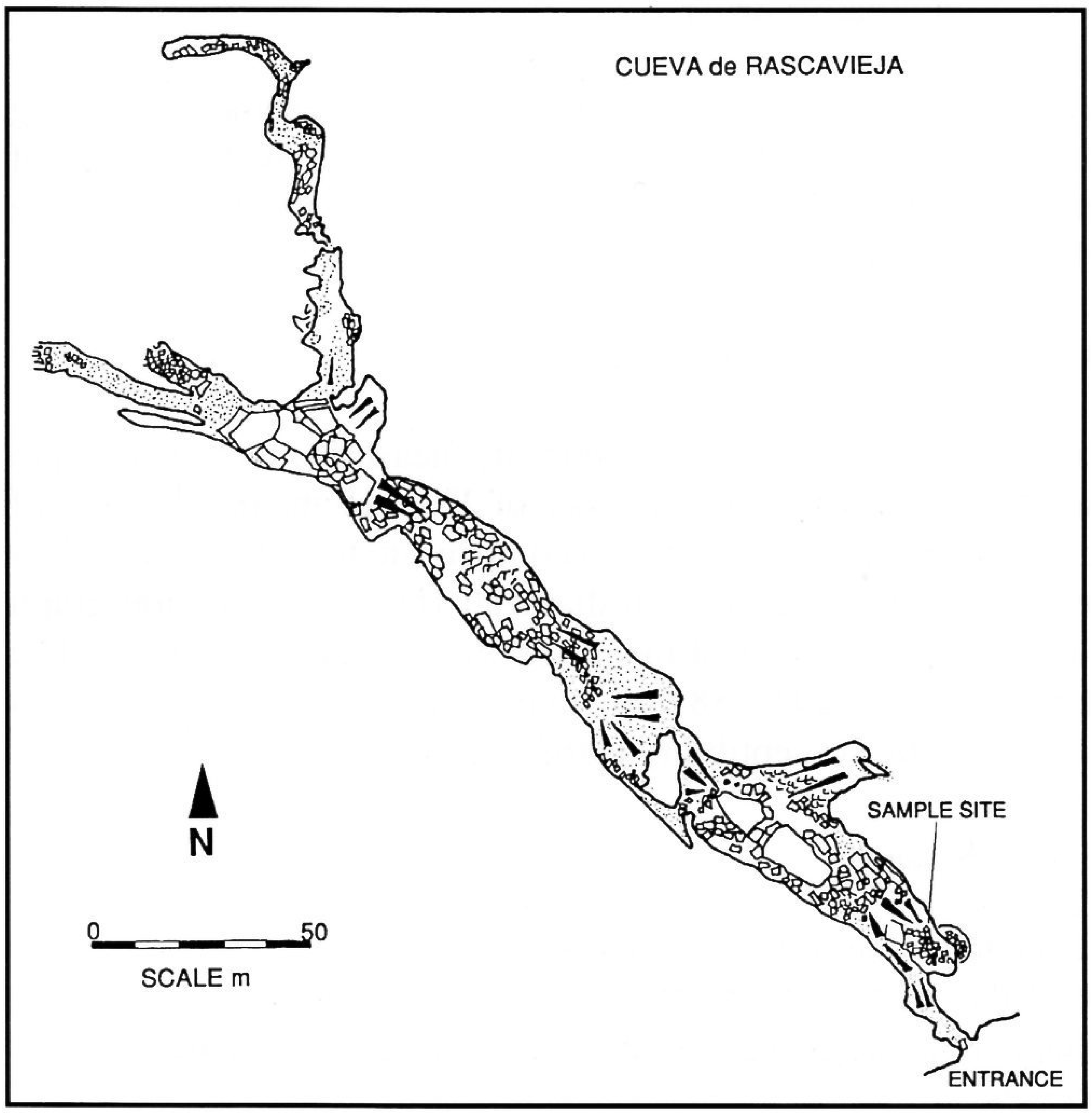

Fig. 9. Position of the sampling site in Cueva de Rascavieja (after an original by P. Smith).

A sampling device was designed and constructed by the author. The sediment receiving component of this is a 1 m long PVC collection tube, which was driven vertically into each chosen sediment bank by means of a hammer and hardwood drift. The orientation and inclination of the sample tube were measured and noted, using alignment slots cut in the top of the device. The front edge of the sample tube was also marked by indelible pen. The collected sample of cave sediment was sealed into the PVC tubing at the sampling site by means of plastic caps fitted over the ends of the tube, and then made fast by a wrapping of insulating tape. Before sealing the top of the tube it was trimmed to the level of the collected sediment to prevent any disturbance of the sample during transport between the site and the laboratory in the U.K. The date of collection, site name and sample number was marked on each sample, using an indelible pen. The sampling point was then surveyed to a known survey station within the cave. If the sediment bank was deeper than the 1 m long collection tube, it was excavated to the depth of the base of the tube after the bank had been sampled to 1 m. The tube was then removed, secured and marked in the way described. The base level of the excavation then presented a new surface from which to take a second core. The top of this second core would then be a continuation downwards from the base of the first.

MAGNETIC SUSCEPTIBILITY MEASUREMENT

A Bartington MS2 magnetic susceptibility meter fitted with an MS2C core sensor was used to measure magnetic susceptibility at 5 mm intervals along the length of each core.

Magnetic susceptibility is a dimensionless parameter dependent on the strength of the magnetic field causing the magnetization. However, it is often given units to distinguish between susceptibilities based on sample mass, and susceptibilities based on sample volume. If k is susceptibility per unit volume, X is susceptibility per unit mass, and R is the density of the sample, then

$$X = k/\mathrm{R}.$$

The MS2C sensor used gives volume susceptibility measurements. To obtain a susceptibility reading (R_S) for a sample, the measured reading (R_m) from the susceptibility meter must be corrected to compensate for drift of the machine during sampling, and the susceptibility value generated by the PVC tubing containing the sample (R_C) such that

$$R_S = R_m - (R_C + \text{cumulative drift}).$$

In all cases $R_C = 0.4$. Drift is calculated by zeroing to air before any readings are taken and then taking a reading to air after the final core reading to give the total drift. The total drift divided by the number of readings taken for a core will give the mean drift over each reading. The drift correction is the cumulative drift at each reading along the core, the final drift correction being the total drift:

$$\text{mean drift} = \text{total drift / no. of readings}.$$

The ambient laboratory temperature variation over the period of susceptibility measuring had a maximum value of 0.5°C. This is well within the temperature fluctuation tolerance of 2° set by the manfacturer of the susceptibility meter. The sample reading must also be corrected to compensate for effects caused by the relationship between the core diameter (d) and the sensor coil diameter (D). A calibration graph plotting d/D against $k_{relative}$ is provided by the manufacturer of the magnetic susceptibility meter. The values used throughout the analysis were d = 42 mm and D = 88 mm, giving d/D = 0.477, which equates on the calibration graph to $k_{relative} = 0.48$ Magnetic susceptibility is then given by

$$k = R_S \times k_{relative}.$$

Variations in magnetic susceptibility depend on the following factors:

- The geographical location of the source catchment
- The length of time for which erosional processes have been acting upon an area.
- The rate of erosional processes
- The position within a soil profile from which sediment material is derived.

The comparison of magnetic susceptibility profiles along sediment cores is to some degree dependent on the values recorded for these cores. If a similar range of values are recorded for each sample the positions of peaks of high susceptibility are likely to be of most interest. The relative position along the length of the cores, of peaks representing a characteristic change in sediment supply, could be compared at various points along the fluvial system. A similar pattern of peaks in susceptibility, but varying in position, may be present in cores taken from different locations along the same fluvial system.

The range of susceptibility values recorded may however differ between sets of samples. In this case sample sites can be grouped according to similarities in their susceptibility ranges.

RESULTS

The core lengths, with maximum and minimum values, and ranges, are given in Table 2.

There is little variation in susceptibility values along the cores taken from **Coteron** (Fig. 10).

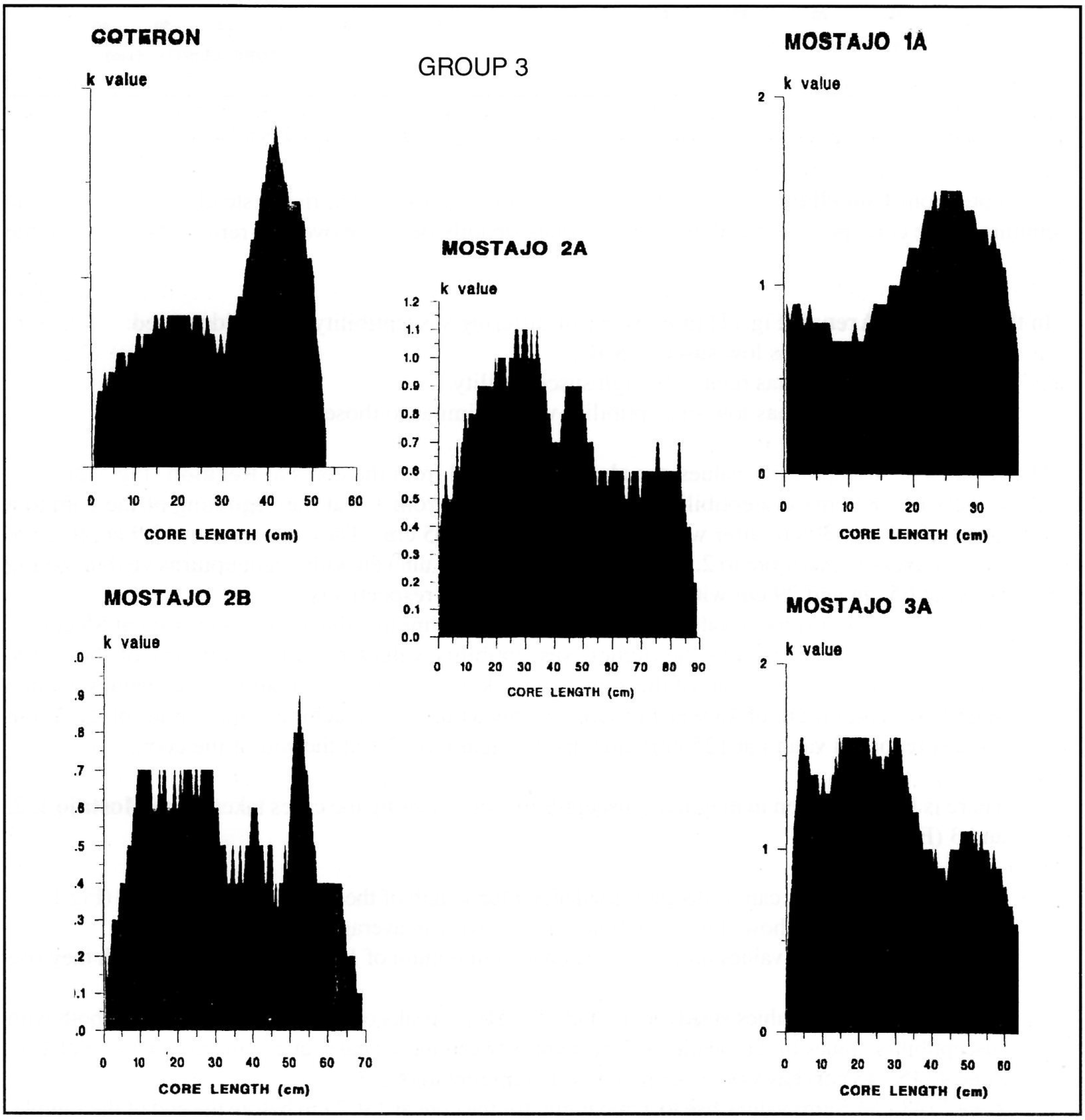

Fig. 10. Magnetic susceptibility graphs for Torca del Coteron and Torca del Mostajo (Group 3).

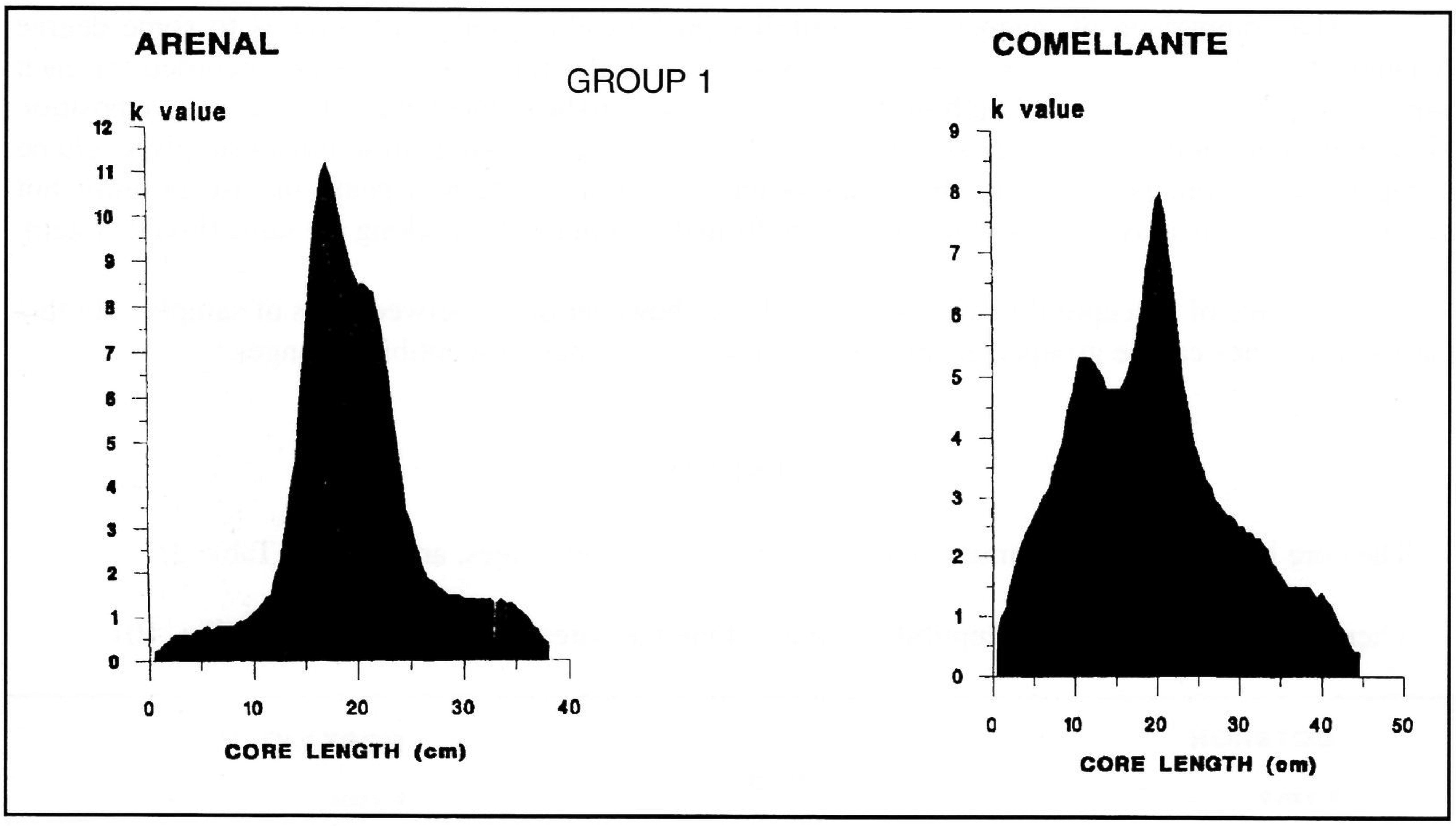

Fig. 11. Magnetic susceptibility graphs for Cueva de Arenal and Cueva del Comellante (Group 1).

The core from **Comellante** (Fig.11) has susceptibility values which, rising steadily from 1.7 at the beginning of the core, peak at 8.0 after 21 cm. Values steadily decrease over the remaining length of the core.

In the core from **Arenal** (Fig.11) three zones of differing susceptibility can be identified:
Zone 1 (0 - 12 cm) has low susceptibility.
Zone 2 (12 - 26 cm) has relatively high susceptibility.
Zone 3 (26 - 35 cm) has low susceptibility values similar to those in Zone 1.

Three zones of susceptibility values can also be identified from the cores at **Regaton** (Fig. 12):
Zone 1 (0 - 83 cm) susceptibility values rise steadily from 1.9 at the beginning of the core to a value of 14.5 at 30 cm after which they fall to 7.5 at 35 cm. They then rise to 12.9 at 39.5 cm. They decrease once more to 2.1 at 83 cm; this decline is uneven with slight upturns visible, giving peaks at 65 cm and 79 cm with *k* values of 3.4 and 2.9 respectively.
Zone 2 (83 - 98 cm) has *k* values below 1.8 with a minimum value of 1.2 occurring at 85 cm.
Zone 3 (98 - 136.5 cm) has the highest susceptibility values recorded from any of the cores. Values rise from 2 at the start of the zone to a peak of 24.2 at 113 cm, after which values decline slightly to a minimum of 18.9 at 115 cm. Values again rise, reaching a maximum of 41.2 (the highest recorded value) at 125 cm), and decline again to 12.1 at the end of the core.

There is little variation in magnetic susceptibility values along the cores taken from **Mostajo** 1, 2, and 3 (Fig. 10).

Five zones of *k* values can be distinguished along the length of the core from **Coberruyo** (Fig.13):
Zone 1 (0 - 13.5 cm) shows little variation in values with an average value of $k = 2.5$.
Zone 2 (13.5 - 17 cm) values drop below 1.8 with a minimum of 1.1 at 15.5 cm after which they rise again.
Zone 3 (17 - 45 cm) values steady at around 2.1. Minor peaks occur at 20 cm and 32 cm, both with susceptibility values of 2.6, while the low point between these peaks, at 27 cm, has a *k* value of 1.9.
Zone 4 (45 - 48 cm) has values below 1.8 with a minimum of 1.7.
Zone 5 (48 - 54.5 cm) values rise to a maximum for the core at 3.9, 2 cm before the end of the sample.

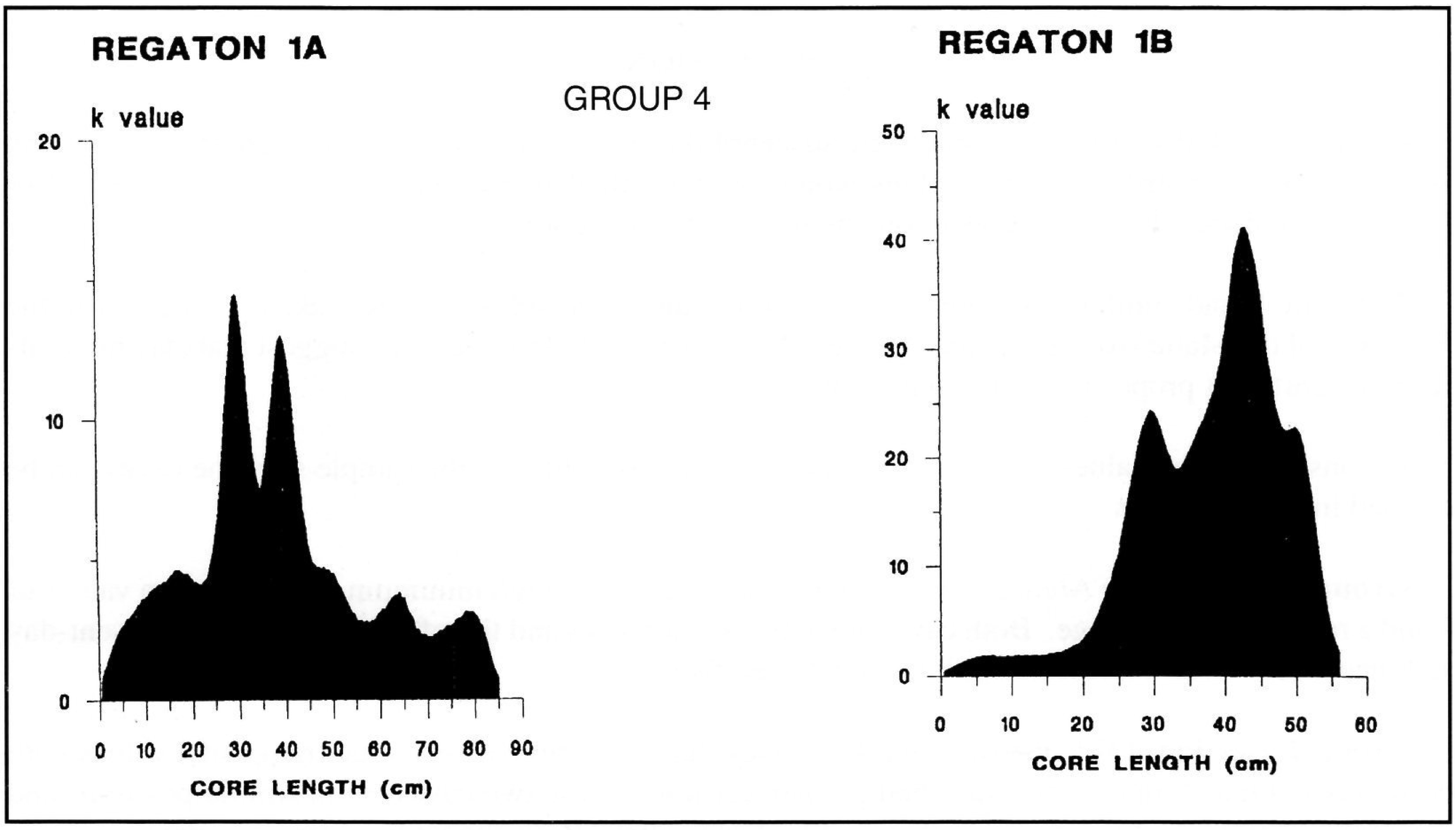

Fig. 12. Magnetic susceptibility graphs for Torca Regaton (Group 4).

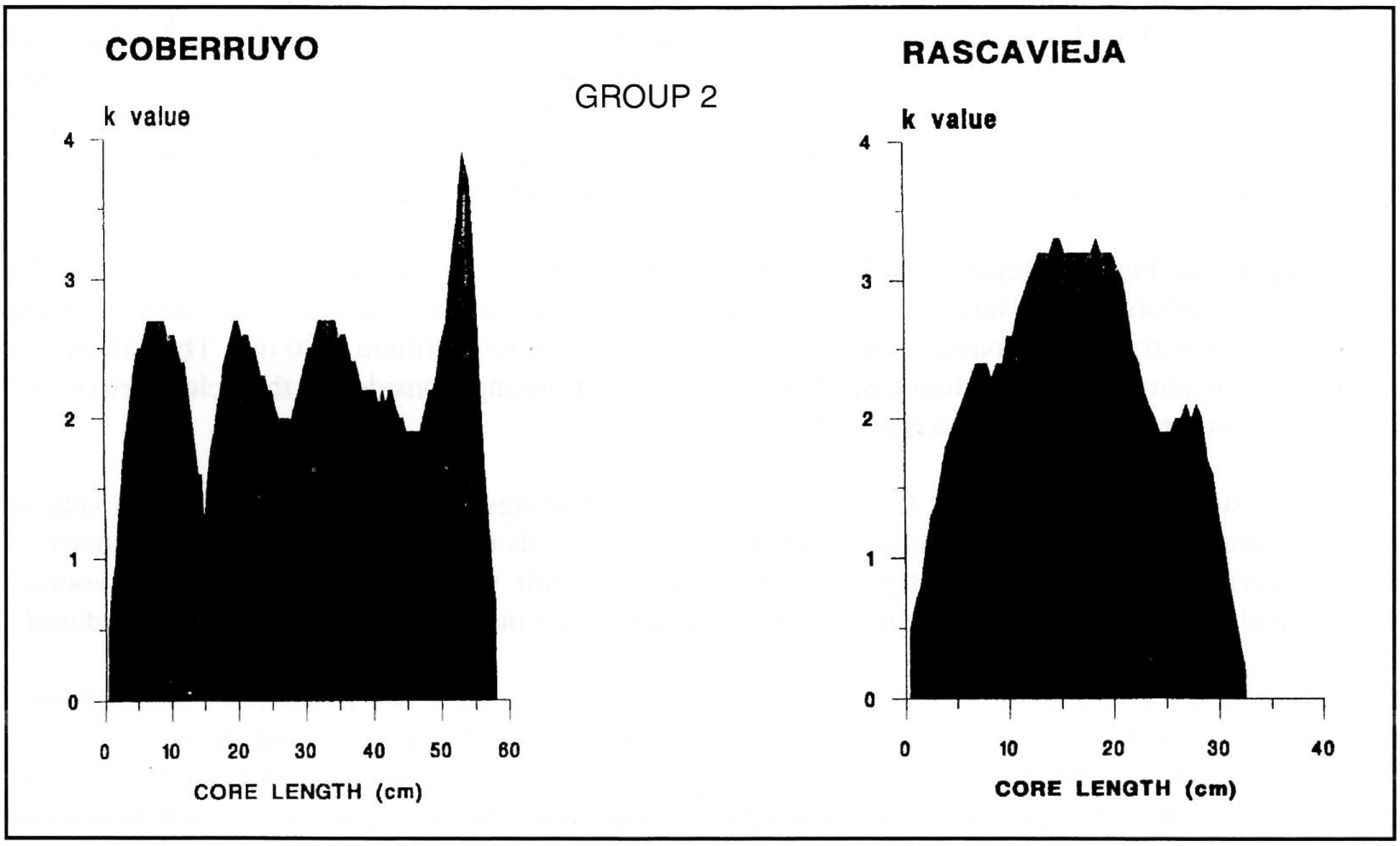

Fig. 13. Magnetic susceptibility graphs for Cueva de Coberruyo and Cueva de Rascavieja (Group 2).

The 29 cm of the core from **Rascavieja** (Fig.13) can be can be considered as a single zone. Values rise from 1.6 to a maximum of 3.3 at 15 cm. Between 13 and 20 cm all *k* values are either 3.2 or 3.3. Values of *k* fall steadily between 20 cm and the end of the sample where *k* = 1.6.

DISCUSSION

Clear trends in the variation of magnetic susceptibility values are seen along the length of each core. A more random distribution of *k* values would have resulted if the sediment had been disturbed or magnetism induced during the collection and transport of the cores.

There are broad similarities among susceptibility values for sediment cores taken from caves in the Vega arm of the Matienzo depression. All the values of *k* recorded for the cores suggest that clay minerals form a significant proportion of the sediments.

In considering the values and ranges of magnetic susceptibility for the sample sites the caves can be divided into four groups.

Group 1 (see Fig. 11) Arenal and Comellante have relatively high minimum and maximum values of *k* and a relatively large range. Both caves are active resurgences and therefore supplied with present-day sediments. No hydrological link is known between them.

Group 2 (see Fig. 13) Coberruyo and Rascavieja have a comparatively small range of *k* values with both maximum and minimum values being relatively low. These two caves are in similar positions and at identical altitudes on the northern slopes of La Vega valley. Both appear to be small, isolated sections of now-fragmented larger systems, and were possibly once connected to each other.

Group 3 (see Fig. 10) Coteron and all sites within Mostajo have very low maximum *k* values and small ranges of values. The two caves are on opposite sides of the valley to each other. Their passages, however, bear some resembances to each other. Large abandoned tunnels with large quantities of sediment deposits are a feature of both. In areas of both, extensive calcite and gypsum deposits are common. The major development of both caves lies between 230 m and 240 m in altitude.

Group 4 (see Fig. 12) Regaton has high maximum *k* values and similar minimum *k* values to all the other sites; therefore it has a large range of recorded values. The cave is unusual for the area in having considerable horizontal cave passage development at a relatively low altitude (180 m). The values of *k* found here compared with those found in Mostajo are quite surprising, considering their close proximity. None of the other sites produced comparable results.

Various suggestions can be put forward to explain the findings of this study. Caves with similar ranges of magnetic susceptibility values in their sediment records (Arenal and Comellante, Coberruyo and Rascavieja, Coteron and Mostajo) may have derived their sediments from a common source. Alternatively two or more source areas of similar characteristics may have supplied sediment material.

It could be argued that even if a common morphogenetic agent formed two caves they could still have developed independently from each other. This would be the case if a river passing through one cave then resurged into a valley floor and later entered the second cave. Several points indicate that this did not occur at La Vega. Caves formed by a sinking river often have vadose characteristics such as notches or incised trenches. These are absent from the caves in question. More convincingly, the general direction of hydrological flow in the region is from south to north, as evidenced by scallop markings in many caves at Matienzo. The proposed links between Coteron and Mostajo have lower passage altitudes to the south, in Coteron. If it is accepted that the direction of flow is from south to north it must have been flowing up a gradient, as happens with water responding to a hydraulic head within the phreatic zone.

CONCLUSION

Without detailed information regarding the age of the deposits it is not possible to make definite links between the morphogenesis of the cave systems investigated. However, with the similarities established between the caves within the four groups, magnetic susceptibility values, visual appearance, altitudes of passage development, and hydrological state (i.e. active or abandoned), such morphogenetic links are probable.

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