The karstic evolution of the Matienzo depression, Spain

by

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with 5 figures and 2 photos

Zusammenfassung. Die Matienzo Depression ist ein großes, geschlossenes Tal im Karst Nordspaniens. Es wird von Rücken begrenzt, die nirgends weniger als 200 m über den Talgrund aufragen. In der Depression sind zahlreiche aktive und fossile Höhlen ausgebildet. Darin sind eingeschlossen sowohl verlassene hochgelegene Passagen als auch ein komplexes System, das die heutige Entwässerung unter der topographischen Wasserscheide abführt. Aufeinanderfolgende Phasen der Höhlenentwicklung haben die Depression in verschiedene benachbarte Täler entwässert. Die bekannten Höhlen sind sowohl vadosen als auch phreatischen Ursprungs, und die Niveaus der Höhlenentwicklung wurden nicht von den gleichzeitigen Höhen des Talgrundes gesteuert. Ohne Anzeichen für glaziale Modifikation ergibt sich durch Extrapolation der Lösungsraten ein Minimumalter von 1,8 Millionen Jahren für die Karstdrainage der Depression. Der älteste bekannte hochgelegene Höhlenrest muß noch beträchtlich älter sein.

Summary. The Matienzo depression is a large closed valley in the limestone karst of Northern Spain. It is bordered by ridges nowhere less than 200 metres above the valley floor. Numerous active and fossil caves are known in the depression. They include both abandonned high-level passages and a complex system taking the modern drainage out beneath the topographic divide. Successive phases of cave development drained the depression to different adjacent valleys. Known caves are both vadose and phreatic in origin, and levels of cave development have not been controlled by contemporaneous valley floor altitudes. With no glacial modification in evidence, extrapolation of solution rates indicate a minimum age of 1.8 million years for the karstic drainage of the depression, and the oldest high-level cave segments known must be considerably older still.

Résumé. La dépression de Matienzo est une grande vallée fermée dans le karst du nord de l'Espagne. Elle est bordée de crêtes, qui dominent toujours d'au moins 200 m le fond de la vallée. De nombreuses cavités fossiles et actives se sont formées dans la dépression. Elles comprennent à la fois des conduits de haut niveau abandonnés et un système complexe drainant les eaux actuelles sous la ligne de partage des eaux de la topographie extérieure. Des phases successives de développement des grottes ont assuré le drainage vers différentes vallées voisines. Les cavites connues sont dues aussi bien à l'écoulement vadose que phréatique et les niveaux de développement des grottes n'ont pas été contrôlés par les altitudes des fonds de vallées contemporaines.

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Sans indications de modifications glaciaires, par l'extrapolation du degré de solution on trouve un âge d'un minimum de 1,8 million d'années pour la dépression. En conséquence les sections de cavités de plus laut niveau doivent être nettement plus vieilles.

The Matienzo depression is a spectacular closed basin of karstic origin. It is unusual in that the cave systems which carry the drainage out of the depression are sufficiently well known to be able to indicate the history and evolution of the landforms of the area.

Matienzo lies in the northern foothills of the Cantabrian Mountains and is some 25 km southeast of Santander (fig. 1). Local relief at Matienzo is nearly

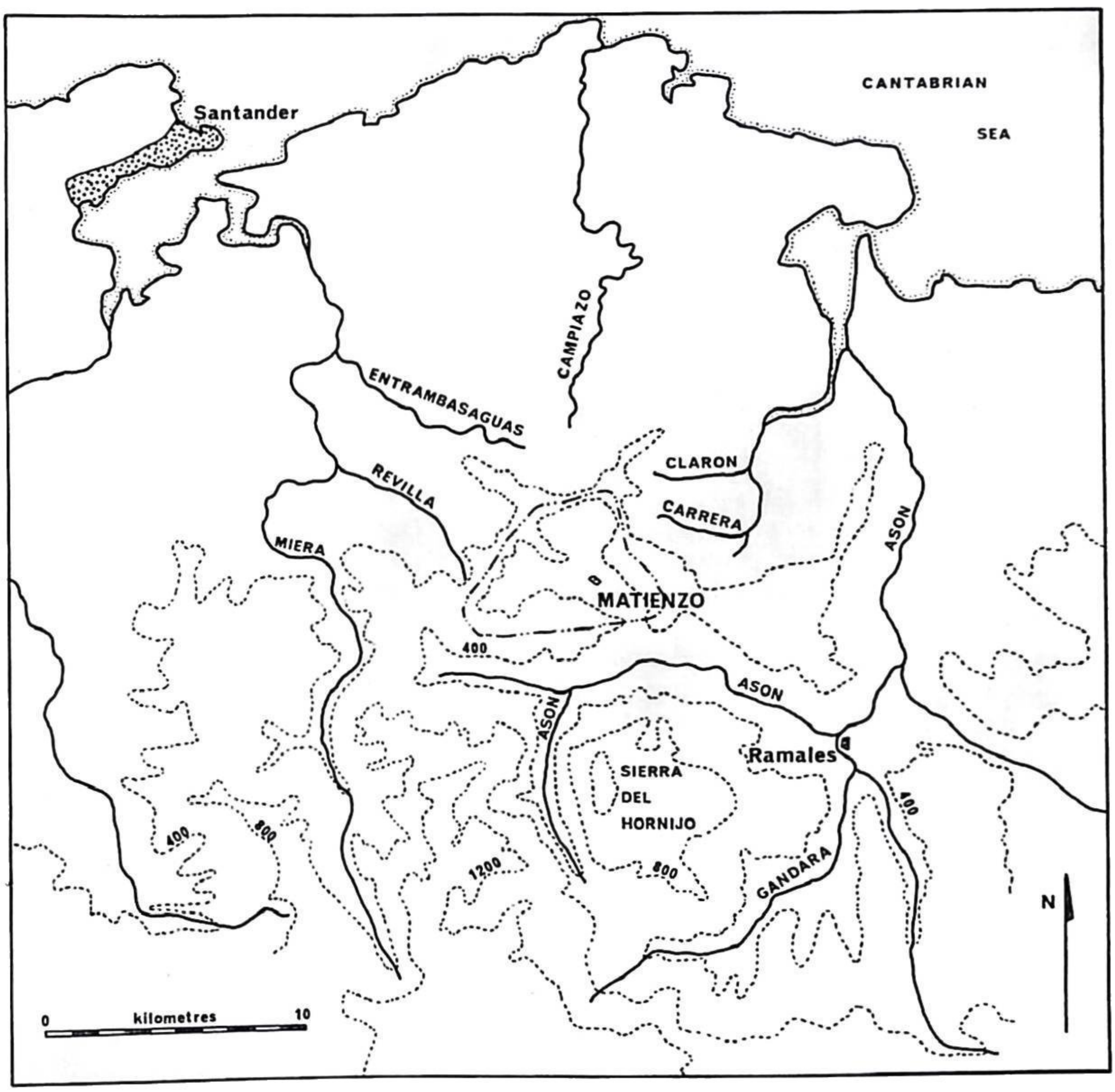

Fig. 1. Location map of Matienzo area.

Photo 1. The Matienzo depression seen from the ridge at its western end. The Vega valley lies in the foreground with Enaso hill on the left and Muela hill in the distance. Beyond Enaso, the col just visible passes over to the Carrera and Claron valleys and the regional drainage outlet.

800 m – with the highest hill at 833 m a.s.l. and the main outlet resurgence cave at less than 50 m. Eight km to the south the main summits exceed 1400 m, while the coast approaches to less than that distance to the northeast. The climate is influenced by the proximity of the Atlantic, and Matienzo receives an annual rainfall of around 1200 mm. For similar reasons temperatures are not as extreme as elsewhere in Spain; summer afternoon temperatures commonly reach 25 °C and, while winters are cool, snow is almost unknown at these altitudes. The hills around Matienzo present a landscape of short grasses, broken by scars of bare limestone with cliffs and patches of grassed scree on the steeper slopes (photo 1). The cultivated and cropped valley floors provide a livelihood for the people of the straggling village of Matienzo. Good but steep roads climb out of the depression from the village.

The closed depression

The area of the Matienzo depression is 26.3 km^2; just over a tenth is occupied by the almost flat valley floor, while the remainder consists of steep hillsides rising to the perimeter ridges. Summits on the ridge rise to altitudes of 517 to 833 m, and there are four main cols on the ridge (fig. 2). The lowest of these, to the south, is at 364 m, more than 200 m above the ponor at the lowest point of the valley.

There are three distinct arms to the Matienzo depression. To the north is the lowest and widest segment, Secada, containing the main ponor at the

northern side of its broad flat floor. Draining into it from the southeast is the gently inclined Ozana valley which descends from the lowest col out of the depression. To the west is the Vega valley, steeply inclined in its upper reaches, but having a long flat floor in its lower reaches, separated by a low rock ridge from the Secada valley. The hillsides are cut by numerous valleys and gullies, most of which are normally dry. The only other large closed valley is that of the Rio Tuerto, separated by a low ridge from a steep descent into the Vega valley.

Almost the whole of the depression is cut into folded Cretaceous limestones, of which there is a total exposed thickness of over 600 m. They are mostly very pure, though parts of the succession contain thin horizons of marl and sandstone. The limestones are mostly rather thin bedded, on the scale of a metre or less, but some beds are more massive and typical of the Urgonian facies. They are folded into gentle east-west synclines with an intervening anticline, with dips mostly in the order of 5 °, but in detail the structure is complicated by extensive block faulting (fig. 3). Though these faults do not have large throws, rotation on them accounts for much of the dip variation across the area. At the foot of the Vega valley, the main anticline brings to the surface the sandstones and marls which underlie the limestone and form an impermeable base to the karst. Except for this small inlier, the only non-calcareous outcrops in the depression are the sediment floors of the Secada and Vega valleys.

Small scale topographic features within the depression are typical of a mature temperate karst. Lapiaz fields are not common, being restricted to the more gently sloping areas mainly along the crests of the marginal ridges. The absence of limestone pavements reflects the lack of glaciation, and the lapiaz is mostly an inhospitable spitzkarren dissected to depths of up to 5 m. Most of the steeper hillsides are covered with limestone rubble, much dating from cold phases of the Pleistocene, with thin soils and sparse vegetation. Cliff lines mark the more massive facies within the limestone sequence. Most of the rainfall sinks straight into the ground. Gullies, active only during heavy rainstorms, abound, but dolines and small blind valleys are restricted in number.

The overall hydrology of the depression is quite simple – centered on the northwesterly flowing Rio Matienzo (fig. 2). Its headwater area is not known in detail as there are no sinks in the area and the main flow emerges from a sump pool in the inner reaches of the Renada cave system. The stream reaches daylight on the south side of the Vega valley then flows down the valley and into a cave cutting through the Enaso hill into the Secada valley. There it is joined by its main tributary, from the Ozana valley where most of its course is underground. The river meanders across the Secada valley to a choked sink-hole which backs up in flood to inundate the lower parts of the valley. From the sink it flows underground through a complex of cave systems to emerge at a large spring, tributary to the Rio Claron, from where it flows to the sea.

The flat, flood-prone, cave-drained floor of the Secada part of the Matienzo depression suggests that it could be called a polje. However the valley lacks the sharply defined slope edges typical of the classical Yugoslavian poljes, and there is no guiding element in the structural geology, so the term can only be applied loosely.

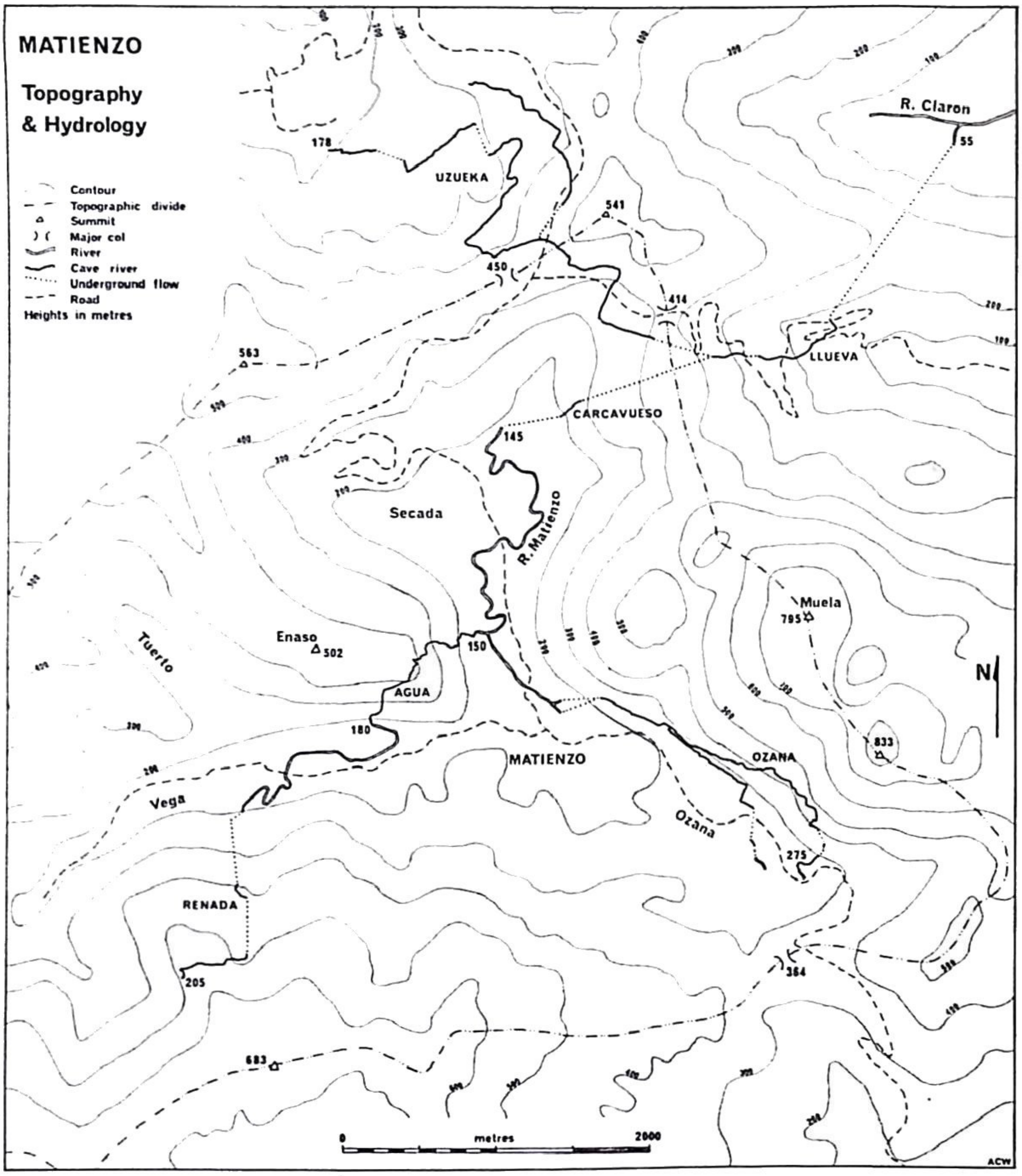

Fig. 2. Topography and main drainage of the Matienzo depression. The western end of the depression continues off the map, but closes in a streamless bowl with ridge elevations ranging from 495 to 778 m.

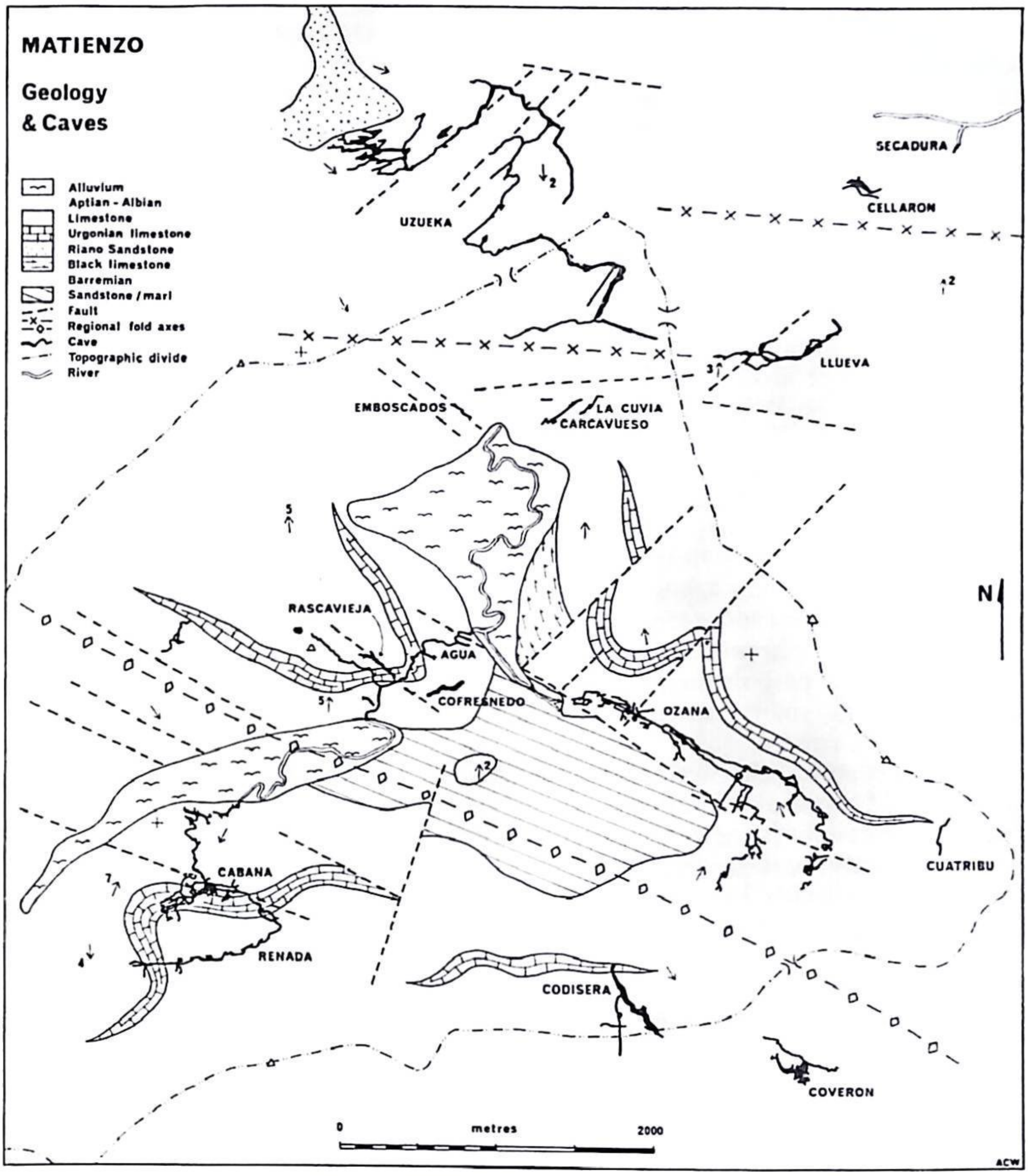

Fig. 3. Geology and major known caves of Matienzo.

Cave development

Over 50 km of cave passages are known to exist in the Matienzo depression, and there must be many more undiscovered caves (MILLS & WALTHAM, in press). (All the main caves are marked on fig. 3 and some appear on the cross section, fig. 4.) Previous descriptions of the Matienzo area pre-date the discovery of most of the caves and therefore lack the more thorough comprehension now obtainable (FERNANDEZ GUTIERREZ 1968).

Only a few of the caves form part of the modern drainage system (fig. 2). All these active caves have gently graded long profiles and have their major sinks and risings at valley floor levels. The Renada cave system is essentially a phreatic fossil network, where the modern stream has invaded and entrenched some of the lower levels. Similarly the Agua cave is an old phreatic passage now largely drained so that the river is vadose throughout except for a 60 m long phreatic segment. The main drainage of the Ozana valley is carried through an integrated vadose cave system not far below the valley floor, but it resurges at a spring on the margin of the Secada valley. Beneath the northern end of the depression only short segments have been discovered of the Carcaveuso-Llueva-Secadura cave system which carries the river to its final resurgence in the Claron valley. Each known segment of cave is similar, consisting of phreatic tunnels incised by vadose canyons, with their explored limits marked by boulder chokes or active phreatic loops. A significant tributary to this system is the Uzueka cave carrying drainage in from the head of the adjacent Entrambasaguas valley. Again the main passages are of phreatic origin now carrying an underfit, largely vadose, stream.

In addition to the active caves, segments of old fossil caves are located around the depression. They are mostly heavily stalagmited and collapsed, so obscuring details of their origins, and it is difficult to relate the isolated segments to any past drainage pattern. Most of them are phreatic, indicating their origins beneath the contemporary valley floors. A large number of the fossil caves are close to the valley floors and no more than 20 m above the

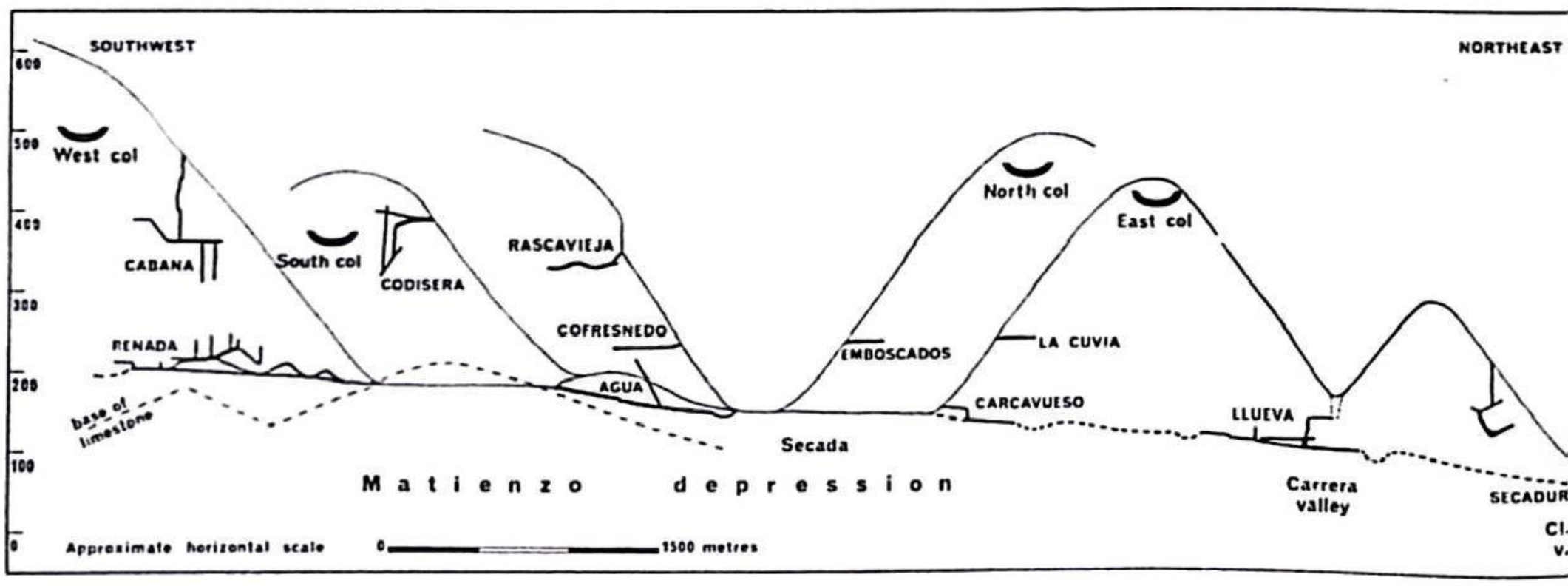

Fig. 4. Semi-diagrammatic section through the Matienzo depression from the upstream limit of exploration of the Rio Matienzo in the Renada cave to its final resurgence at the Secadura rising.

active cave levels. The uninvaded segments of the Renada cave are of this form, as are the extensive fossil passages in the Ozana cave system. But other abandonned caves range to considerable heights above the modern valley floors, with a significant concentration around an altitude of 400 m. There are however no known vadose-phreatic passage junctions which could indicate the precise levels of past water tables.

On the broad scale the patterns of cave development have been primarily controlled by the topography. Underground drainage of sizeable areas has been directed through a continuous limestone mass towards the nearest and lowest available valley. With the Ason, Carrera, Claron, and Entrambasaguas valleys all deeply incised adjacent to the perimeter ridge of the Matienzo depression, there has therefore been considerable scope for complex and changing cave drainage patterns. Within these overall topographic restraints, the geometry of the cave passages has been considerably influenced by the local geology. Bedding planes and sandstone intercalations are the dominant controls and some of the caves maintain remarkably uniform stratigraphic levels. This has therefore favoured down-dip development and a concentration of caves into the synclinal troughs, the northern one of which fortuitously coincides with the lowest valley – that of the Rio Claron. However the phreatic origins of the caves suggest, in their lack of gravitational control, that the synclinal concentration of the karst drainage is subordinate to the topographic influences.

Early drainage patterns

While the Matienzo depression is now clearly recognizable as a karstic feature, it is relevant to determine from what nature of landscape it has evolved. There is no evidence of Pleistocene glaciation at altitudes as low as even the hills surrounding Matienzo. Small Pleistocene icecaps developed on the mountains around the Sierra del Hornijo and though glaciers flowed into the valleys they did not reach north of the Ason river. The Matienzo depression developed from a fluvial regime.

The orientations of the early drainage of the area, 200–300 m above present valley floors, is not easily determined. MUGNIER (1965) suggested that the River Ason initially flowed across the Matienzo region and out to sea down the Campiazo valley, before its capture and diversion towards Ramales (fig. 1). There is only very tenuous evidence for this in the form of graded profiles constructed on widely spaced col heights and some remnant sediments apparently lacking imbrication. It is just as credible to consider the middle Ason as a major subsequent tributary to the Gandara-Ason consequent through Ramales. Drainage of the Matienzo area would then have been both north and south off the Vega anticline. Whichever of these patterns did exist, it was then destroyed when the thick limestones were adequately exposed and underground capture took place. The consequence of this was the topographic isolation of the depression and its continued development in a purely karstic environment.

Development of karst drainage

Underground drainage was initiated when suitable cavernous limestones, in structural continuity, were exposed in both the valley floor at Matienzo and a lower valley floor elsewhere. No significant geological barriers existed in the karst and the critical controlling factor at this initial stage was therefore the hydraulic gradient between input and output outcrops. In this respect the deeply incised nature of the adjacent valleys was most important. Major karst drainage outlets have existed to both the Ason and Claron valleys. The Carrera and Entrambasaguas valleys have played less clearly defined roles, and there is no evidence of any karst connections from the Matienzo depression to either the Campiazo or the Revilla valleys. Since the karst drainage was established there is no evidence of a resumption of surface drainage from Matienzo even though underground capture switched the outflow from one valley to another.

Of the various fossil cave remnants at high levels in the depression walls, the only ones that clearly indicate an ancient main drainage outlet are at the southern end. There the caves of Codisera and Coveron represent fragments of an old passage descending from around 400 to 250 m altitude well placed to drain a high level Matienzo basin into the Ason valley, through the modern watershed. This route would have been structurally favoured by its down-dip orientation. Little can be said of its age except that its lower levels are phreatic, so its resurgence level, almost certainly at contemporary valley floor level in such a massive limestone, must have been around 200 m above the present Rio Ason. This early southward drainage suggests relatively deep incision of the Ason and contradicts any suggestion of the proto-Ason flowing across Matienzo to the Campiazo valley for any significant length of time.

All the main low-level cave passages under the north end of the Matienzo depression are of phreatic initiation. The main network lies between altitudes of 100 and 200 m, and at its time of development, the outlet valley floors must have stood above the higher of these levels, to allow ponding within an extensive phreas. The Carcaveuso cave took the main water out of Matienzo, and was joined deep under the limestone ridge by water from the upper Entrambasaguas valley draining through the Uzueka cave. This shallow phreatic system extended to incorporate the upstream phreatic tunnel and then the main passage in the Llueva cave, but beyond there its course is unknown. It may have risen to a resurgence at the head of the Carrera valley, or it may have passed straight through to a lower rising in the Claron valley. Which of these took place was a function of the relative stages of lowering of the two valleys, and at present this cannot be determined though future exploration in the intervening ridge may reveal an answer. Ultimately the rising in the floor of the Claron valley was lowered enough to permit partial drainage of the caves and the onset of vadose conditions in all except a few deeper parts of the initial phreatic pathway. Some passages have been abandonned but much of the present drainage is along incised floors in the old phreatic caves.

The caves of the Enaso hill indicate successive stages of phreatic drainage of the Vega valley as its floor was progressively lowered. At all times, as now, these have drained into the Secada part of the Matienzo depression, and it is

the floor levels of this which must have dominated the levels and nature of the cave development.

It is significant that nowhere in the Matienzo depression are there known caves which can be seen to have developed at any water table within the limestones. Water surface wall notches are not found in the caves and the long profiles of the phreatic caves do exhibit considerable vertical relief, commonly in the order of 30 m or more. This is small compared to the total thickness of the limestone so it could be claimed that many of the caves have a shallow phreatic origin, but water-table or epiphreatic caves have not developed. Valley floor levels, and resurgence levels, have only exercised a very broad control over levels of cave development; the morphological details are geologically controlled. In contrast the caves appear to have influenced valley floor levels. Deepening of the Vega valley is now essentially dependant on downcutting of the floor in the Agua outlet cave. The floor of the Vega valley has been lowered to, and not below, the level of an old cave passage which was formed under phreatic conditions at a level dictated by vagaries of the geological structures. Similarly the erosion or further alluviation of the Secada valley

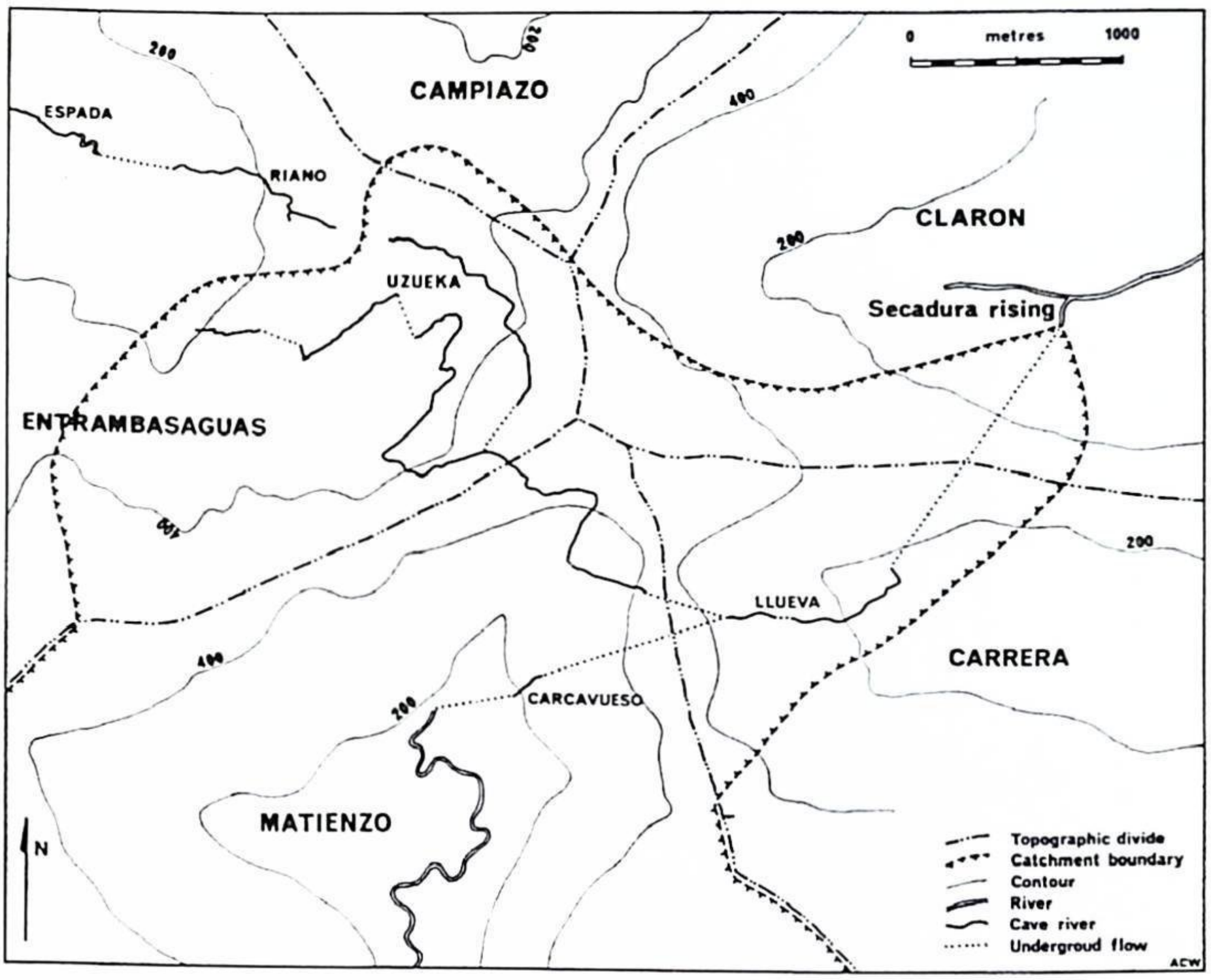

Fig. 5. The northern end of the Matienzo depression with the catchment basin of the Secadura rising including parts of five topographic basins. Practically the whole of the Matienzo depression must be included in the Secadura catchment but its own drainage limits are not known in detail.

floor is related to the levels of rock lips on the floor of the drained phreatic cave of Carcaveuso.

A consequence of the mature karst development has been the generation of drainage catchment areas with total disregard for surface topographic basins. At the northern end of Matienzo, five topographic ridges converge (fig. 5). Parts of all five intervening topographic basins drain to the Secadura resurgence in the Claron valley. The catchment area for this important karst rising includes the whole of the Matienzo depression and much smaller areas in the adjoining valleys which drain through the Uzueka and Llueva caves. The catchment boundary shown in fig. 5 can only be drawn approximately, but it is based upon the distribution and sizes of the known cave streams and the knowledge that most percolation drainage is almost vertically down joints or offset in the direction of dip.

A time scale for the depression

The Matienzo depression is distinctive in having clearly defined boundary ridges, high cols in these ridges, and a clear lack of any Pleistocene glacial excavation. A chronology back to its early stages of development can therefore be based on extrapolated erosion rates.

The lowest col out of Matienzo is at the south end, at an altitude of 364 m. At a minimum, the depression below this level must have been excavated and then transported away by the underground karst drainage. The volume of the depression below the 364 m level is approximately 1360 million m^3. Present erosion is dependant on an annual rainfall of 120 cm, of which about 50 % is lost by evapotranspiration, over the depression area of 26.3 km^2. This gives an annual outflow of 15.6 million m^3, or 0.5 cumecs, which is a roughly estimated annual mean flow through the sole outlet of the valley in the Llueva cave (photo 2). The water in the Llueva and Secadura caves has not been analysed, but figures from resurgences in adjacent areas suggest an average calcium carbonate solute concentration of around 130 p.p.m. This would give an annual limestone transport out of Matienzo of 2000 t. Taking a limestone density of 2.65, this means that present erosion rates would have taken 1.8 million years to excavate the closed portion of the Matienzo depression.

This age determination requires a number of qualifications:

a) the volume of the caves is ignored as they are trivial by comparison;

b) the climate is assumed to have remained constant; however, during the Devensian and earlier cold stages of the Pleistocene, the area was one of tundra with consequently much lower solution rates, and this would more than compensate for any phases warmer or wetter than present;

c) no mechanical erosion of the limestone is allowed for in view of the lack of totally vadose drainage at any time in the past; suspended sediment loads in limestone catchments are normally only a small proportion of the total erosional transport (NEWSON 1974), and, in addition, phreatic segments in all the outlet systems known would have acted as sediment traps efficient enough to make sediment account for no more than a few per cent of total erosion;

Photo 2. The main drainage outlet for Matienzo in the Llueva cave, looking upstream. The roof has been modified by collapse and the river is beneath the boulders at this point.

d) the valley floor is presumed to have been level and bounded by the present 364 m contour at the time of karstic capture; this is patently untenable, and the volume of rock which must have been removed above this surface must considerably lengthen the period of karst excavation of the depression, given the same erosion rate.

A minimum age of 1.8 million years is therefore claimed for the onset of karst drainage at Matienzo. With reference to qualification (d) above, and even allowing for some mechanical transport through the caves, a figure in the order of 2 million years is very reasonable, and karst processes, involving the earliest exposed limestones and the highest cave fragments now known, must go back considerably further. This long period of uninterrupted karst development is the main factor distinguising the Matienzo depression from its much smaller counterparts in the glaciokarst regions further north in Europe.

Conclusions

Matienzo can be summarised as being a very fine example of a large karstic depression which can be shown to have a long geomorphic history. The whole of the Pleistocene, without glacial interruptions, was involved in the karstic excavation of the depression. Cave systems have been and still are integral

features of the morphology. On the large scale their locations have been dictated by the availability of adjacent valleys suitable to accept the karst drainage, though in detail their patterns are influenced most by the geology. Levels of cave development have not been dependant on valley floor levels in the depression, but the converse has applied and caves have exercised an influence on surface topography. The morphological details of the Matienzo depression exhibit textbook examples of a closed valley, and of a karst drainage network which totally disregards topographic divides.

Acknowledgements

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