Exploration Projects

Five years of speleological investigation in the karst of Sierra Mixteca-Zapoteca, South of Tehuacàn, Mexico

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Contenuto: Resoconto dei risultati delle spedizioni nella Sierra Zapoteca- Mazateca, con la descrizione delle grotte esplorate.

Contents: A report of the results of the expeditions in the Sierra Zapoteca-Mazateca, with the description of the explored caves.

Key-words: grotte idrotermali, forme carsiche, cavità relitte, hydrothermsal caves, karst landforms, relict caves, Juquila Canyon, Tehuacan, Puebla, Mexico.

Year: 2007

Reference: Proceedings of XV° International Congress of Speleology – Kerville, Texas (USA), vol. 3, 1904-1910.

(Published on: Proceedings of XV° International Congress of Speleology – Kerville, Texas (USA), vol. 3)

FIVE YEARS OF SPELEOLOGICAL INVESTIGATION IN THE KARST OF SIERRA MIXTECA-ZAPOTECA, SOUTH OF TEHUACÁN, OAXACA, MEXICO

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Abstract
Since 2002, the Italian team "La Venta" is carrying on a research project that aims to investigate the karst systems in the Sierra Mixteca-Zapoteca, located south of Tehuacán. The Sierra consists mainly of Cretaceous limestone, covered by Upper Cretaceous marly limestones and Tertiary calcareous conglomerates. The most karstified area is the limestone plateau crossed by the Río Juquila (or Xiquila) Canyon. Presently, five missions, performed in the years 2002, 2003, 2004, 2006, and 2007 have discovered more than 70 caves. Despite the good karst potential of the area, large underground systems have not yet been discovered. The longest cave is located in the middle part of Juquila Canyon and consists of a large relict phreatic conduit more than one kilometre long. The deepest caves, vadose in origin, are placed in the high area of Cerro Granudo and in the southeast area, between the canyon and the village of Santa Maria di Ixcatlàn. Some of these vertical caves have deep pits, which are clogged at bottom by debris and mud deposits carried in by runoff water. The Cueva de la Laguna Prieta, for instance, which opens as a wide collapse sinkhole at 2490 m a.s.l., displays a first shaft of 210 m, whereas the cave is 280 m deep. In the area just northwest of Santa Maria, some caves of thermal origin were surveyed during the 2006 mission. These caves display morphologies formed by underwater solution processes, which probably resulted from a rise of hypogenic waters. The caves are remnants of old hydrothermal karst system, presently modified by seepage waters and filled by deposits. During the last mission in November 2007, the higher part of the Juquila Canyon, named Río Matanzas, was explored. This area is characterized by a very deep gorge more than ten kilometres long whose cliffs present some big caves that represent the relict of an ancient phreatic system. Those caves are filled by speleothems and re-crystallized calcite deposits. Finally, many caves show ancient traces of human's frequentation, such as graffiti, wall paintings and jars, usually close to ruins of pre-hispanic (Ñuiñe culture) settlements.
Keywords: karst, hypogenic caves, cave explorations, Tehuacán, Mexico.

1. Introduction

The Tehuacán-Cuicatlán valley, in the north of the state of Oaxaca, is a NNW-SSE tectonic basin bordered by the Sierra Mixteca-Zapoteca on the western side and by the Sierra Mazateca, the Sierra de Juarez and the Sierra de Zongolica on the eastern side. The eastern ridges are made up mainly by Jurassic-Cretaceous limestone and the karst is present with majestic underground systems. The Sierra Juarez-Mazateca hosts the deepest caves of the whole American continent, the Cheve System (-1484 m) and the Huautla System (-1475 m) with tens of kilometres of explored passages. In contrast, the western mountains do not display relevant karst landforms. In order to investigate the sierra located west of Tehuacán, the “La Venta” Geographical Association performed five speleological expeditions from 2002 to 2007 (De Vivo, 2003; Bernabei et al., 2003; Mecchia & Piccini, 2006, Piccini et al., 2008; Sauro, 2008) focused on the central area of the mountain chain. This part is a wide limestone plateau, with mountains passing 2600 m in altitude, crossed by the Rio Juquila (or Xiquila) from SW to NE. The river drains the waters of a wide highland area towards the Rio Salado, in the Cuicatlán valley, a river flowing into the Gulf of Mexico. Limestone outcrops on a surface of about 450 km^2, but field investigation has revealed that karst forms are concentrated in a few limited areas.

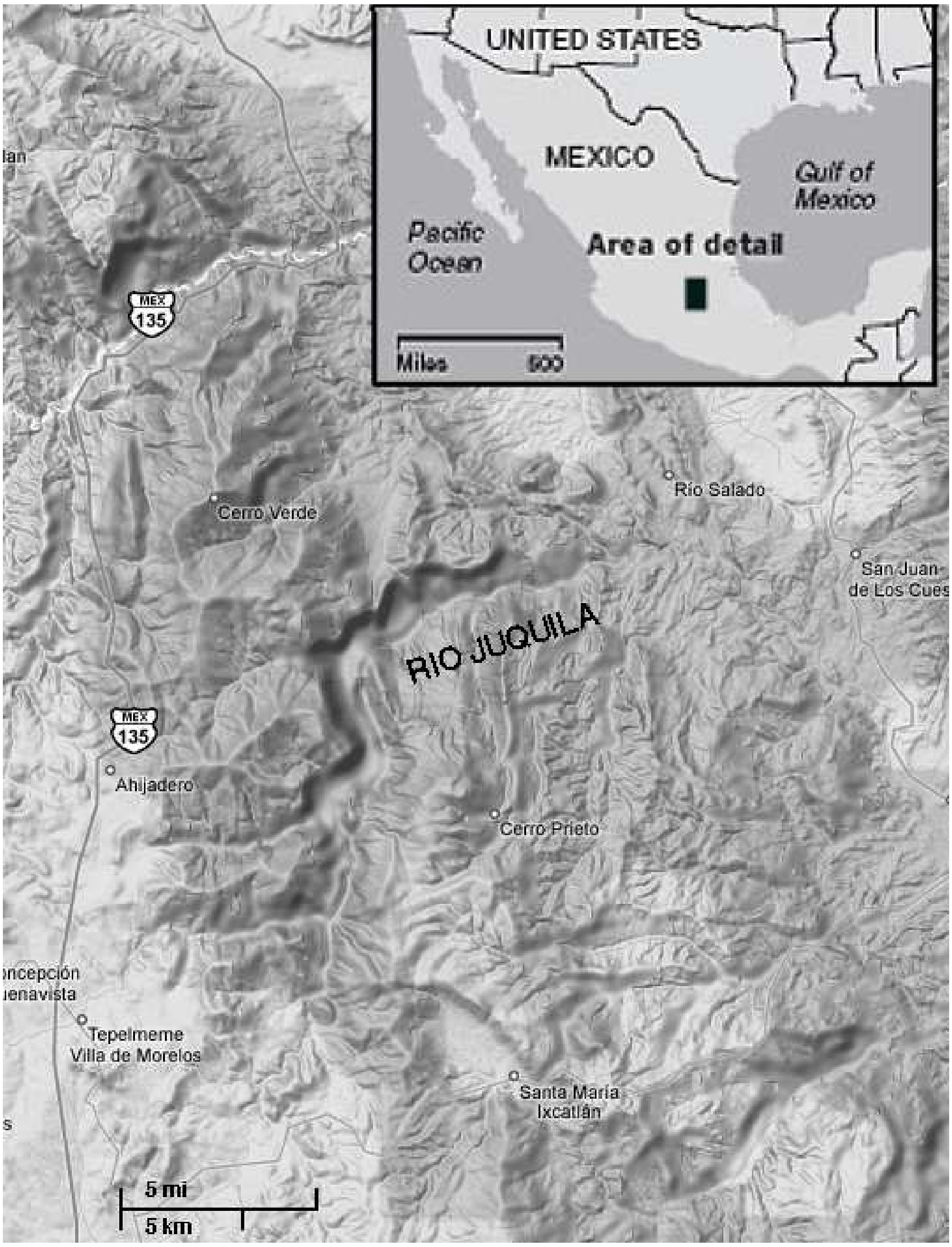

Fig. 1 – Sketch map of the investigated area.

2. Geographical setting

The studied region is a small part of the whole karst area that develops for about 200 km from the west of Tehuacán (Puebla) in the north to the city of Oaxaca in the south. From an administration point of view, the region belongs to the communities of Tepelmeme de Morelos and Santa Maria Ixcatlán and is part of the protected semi-desert area of the Reserva de la Biosfera de Tehuacán - Cuicatlán, world known for its many endemic species of cacti. Geographic and climatic isolation of the valley contribute to a high level of endemism. Mountain ranges surrounding the valley reduce the influx of tropical maritime moisture. Just east of the valley, slopes of the southern Sierra Madre facing the Gulf of Mexico (Sierra Mazateca), receive an annual average precipitation of more than 4000 mm and support tropical rainforest. In contrast, the ranges west of Tehuacán basin are characterised by a semi-arid climate, with rainfalls ranging from 250 to 500 mm, depending on the altitude, concentrated in the months from June to September. Since there are no pluviometric stations, it is not possible to give a reliable evaluation of the rainfall, but on the highland above 2000 m altitude it could reach 500-600 mm per year.

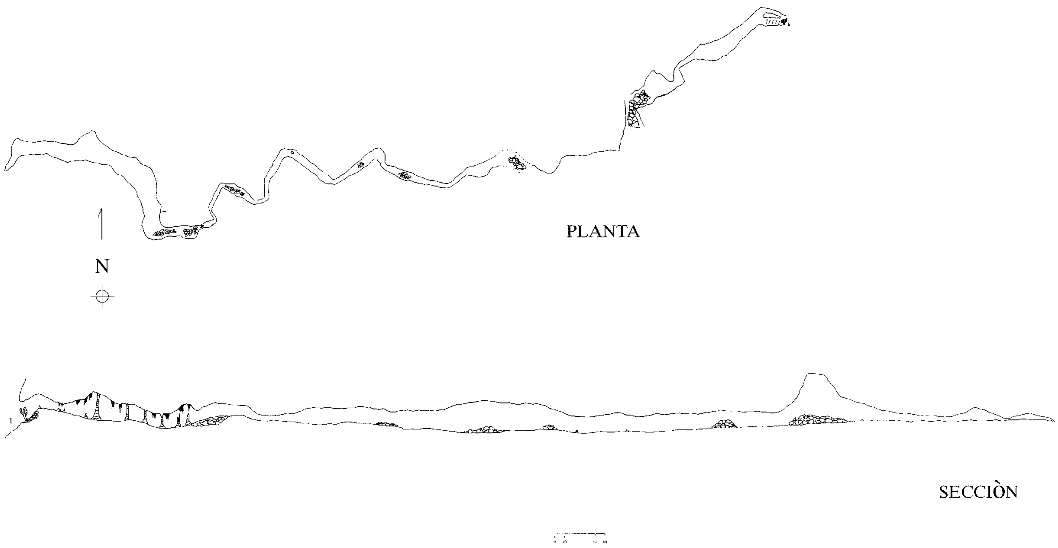

Fig. 2 – Longitudinal profile and plan view of Cueva Dos Ochos (survey: La Venta E. G., 2003).

3. Geological framework

The Late Cretacic Laramide orogenesis produced the main tectonic compressive structures of the Mixteca-Zapoteca range, whereas the Oaxaca normal fault is the regional structure responsible of the neotectonic evolution. The latter is a complex deformation zone that consists of faults having mainly NW-SE directions in the northern segment and N-S directions in the southern one (Nieto-Samaniego et al., 2006). The Mixteca-Zapoteca carbonate range lies west of the fault, which also forms the eastern edge of the Tehuacán valley. At the end of the Paleocene - beginning of the Eocene, an extension phase started, producing the deepening of the Tehuacán valley. This

distension phase was accompanied by volcanic activity of andesite type lasting until the Oligocene (Martiny et al., 2000).
The Sierra Mixteca-Zapoteca consists mainly of an Early Cretacic calcareous sequence, about 1000 m thick, characterised by mainly detritic and bioclastic facies, which lies on Cretacic marls and shales.
In the canyon area, and particularly east of it, we found bioclastic calcarenites and calcirudites with decimetric to metric thick beds with megabreccias bodies and frequent horizons enriched with cherts nodules and rare interlayers of yellowish clay. In the western sector of the area we found well stratified limestone, with abundant cherts, often interlayered with marly and shaly beds. In the eastern sectors of this area Upper Cretacic limestone crops out. A Tertiary (Paleocene – Oligocene) terrigenous sequence, consisting mainly of marls and sandstones, overlies calcareous formations in the south-western sectors of the Juquila basin. Beds are moderately westward dipping. The limestone massif is cut by several faults, prevalently NNW-SSE oriented, parallel to the master faults of Tehuacán basin. Other faults have an orientation E-W. The river network is mainly developed along faults and it shows an angular pattern.
In many places, wide debris deposits due to the intense physical weathering cover the bedrock. These detritic deposits are responsible for the filling of inner basins. The slope debris forms well-cemented covers, typical of semi-arid mountain environments, which probably hide many ancient karts landforms.

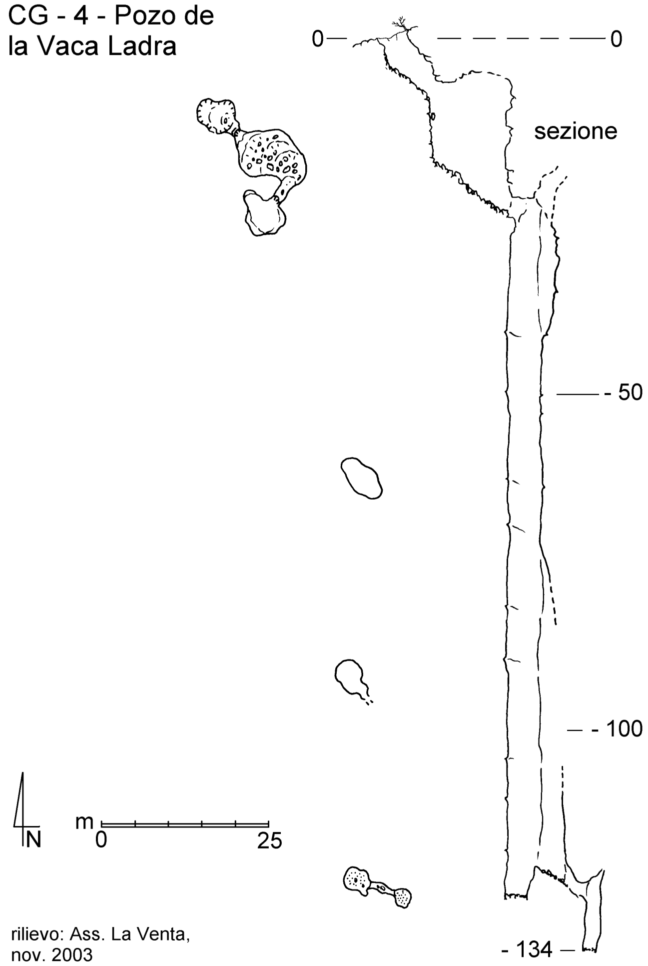

Fig. 3 – Longitudinal profile and plan view of Pozo de la Vaca Ladra (survey: La Venta E. G., 2003).

4. Cave surveying results
The investigated area may be subdivided into three sectors: 1) Juquila canyon, 2) left hydrographical side highland, 3) right hydrographical side highland (Fig. 2).

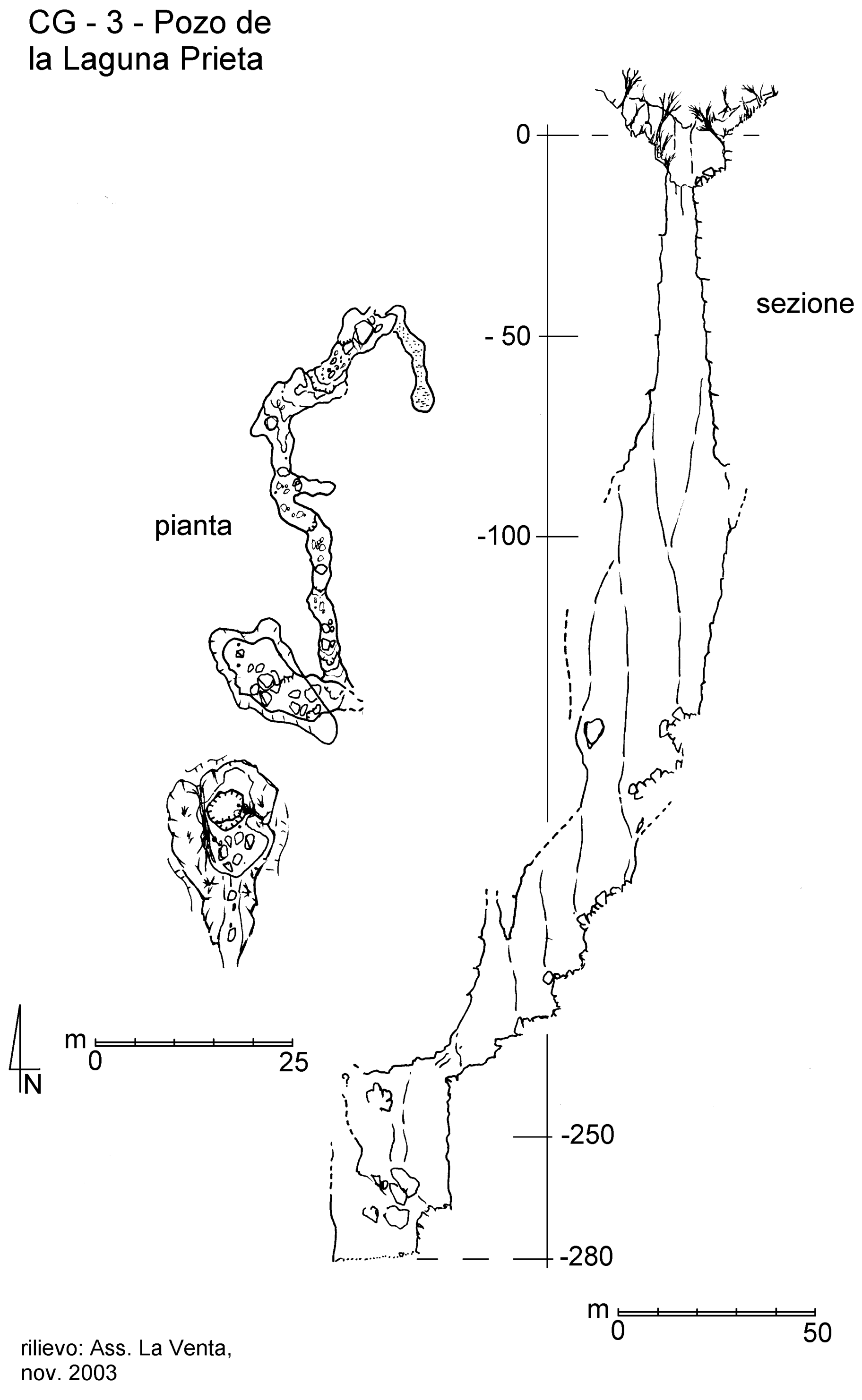

Fig. 4 – Longitudinal profile and plan view of Pozo de la Laguna Prieta (survey: La Venta E. G., 2003).

The Juquila canyon

The Juquila canyon is one of the most impressive of the Sierra Mixteca-Zapoteca. Both sides are steep, sometimes forming almost vertical walls up to 500 m high. It starts from the junction between two secondary rivers, Rio Matanza and the Rio Grande de San Miguel, coming from the terrigenous impermeable Triassic sequences that characterises the western sector, toward Tepelmeme, and the southern sector, toward Santa Maria Ixcatlán. Both these rivers, where they meet the Cretacic limestone, at altitudes of about 2100 metres, fall into long and narrow gorges delimited by more than 100 metres high walls. After a dozen of kilometres of lakes and waterfalls, the two rivers flow into each other becoming the river Juquila. The main river flows all the way down for more than 20 kilometres of canyon to the more open sector of La Huerta springs, located at an altitude of approximately 1200 m a.s.l. Several springs flow out from both sides of the riverbed at La Huerta. In this area, in fact, the canyon incision reaches a less permeable layer, which consists of limestone, marl and sandstone, underlying the strongly karstified limestone that forms the walls of the canyon and the plateau. The total discharge of the springs is not known, although it is still a reasonable amount even in the driest periods. According to the available information, there is not much difference between the dry season flow and the wet season one. One of the spring-caves is located on the western side and may be accessed for about 70 m up to a final sump. During winter 2003 its water flow was some 30-40 litres per second.

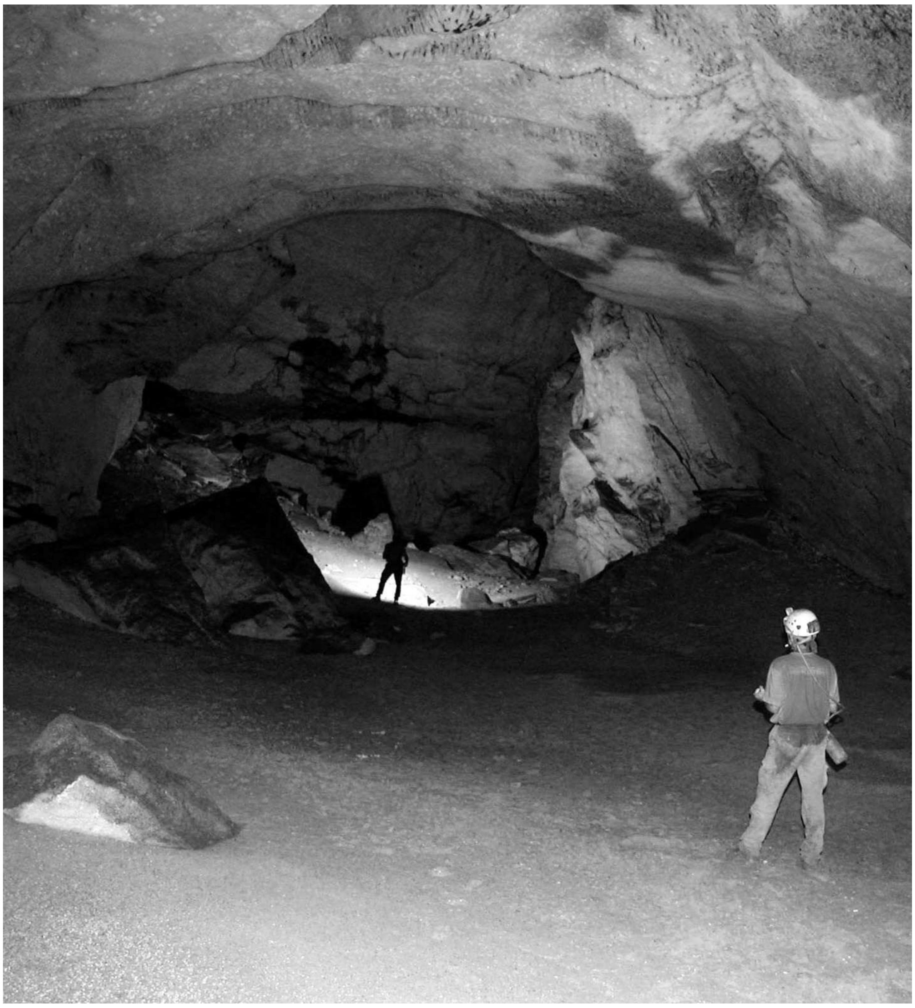

Fig. 5 – Big paleo-phreatic gallery in the Cueva Dos Ochos (photo: Giuseppe Savino, La Venta).

All along the canyon several cave entrances may be found either close to the riverbed or on its steep slopes. In the upper part of the canyon, from Rio Matanza to the central part, at an altitude between 1950 and 1600 m a.s.l., 12 caves have been explored during the last 2007 expedition. In this sector the caves are prevalently relics of vadose systems, with high inactive meanders and pits cut by the development of the Matanza’s gorges, and relict caves in the walls with remarkable concretional deposits. We believe that some parts of this narrow canyon had been a huge cross-cave which was then uncovered by successive collapses of its vault. A similar phenomenon is visible in its majestic form in the central part of Juquila Canyon, after the confluence between Rio Matanza and Rio Grande. A very interesting cave, well known since a very long time, is located in a tributary canyon that cuts down the limestone massif near the village of Puerto Mixteco. This cave is locally renowned as Puente Colosal (PC), and consists of a natural 250 m long tunnel. This impressive gallery, located at the end of a blind valley, is up to 50 m high in the final part and never less than 15 m wide. Nuiñe paintings and inscriptions are present on the gallery walls; the archaeological studies date them between 300 and 800 A.D. (Mautner, 2005; Urcid, 2004). Today the cave is completely dry, except during strong floods. From Puente Colossal to La Huerta, at altitudes between 1600 and 1400 m a.s.l., nine caves have been explored. These are short segments of old phreatic tubes, up to 10 m in diameter, closed by fluvial deposits, flowstones or rock falls after a few dozens of metres of length. The longest cave is the Cueva Dos Ojos, located on the left side almost 300 m above the active springs. This is an almost straight dry gallery, about 1 km long, which presents clear phreatic features.

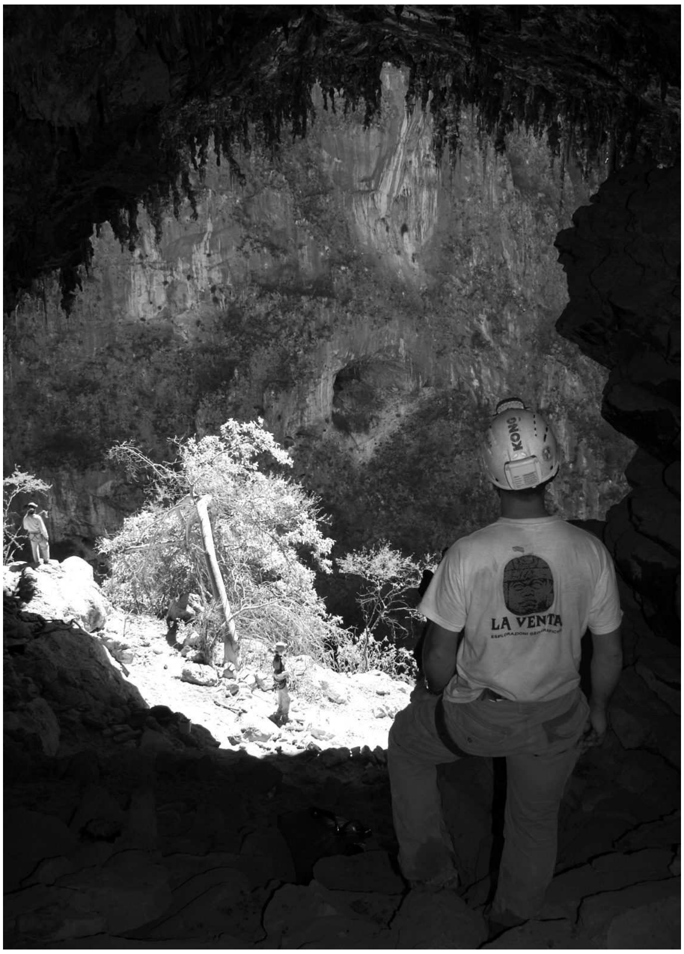

Fig. 6 – The entrance of Cueva del Pueblo, a paleo-phreatic gallery cut by the deepening of the Juquila Canyon (photo: Francesco Sauro, La Venta).

Left hydrographical highland

The western section of the limestone range consists of a 15 km long ridge connecting, from south to north, Cerro Tequelite, Cerro Pericon and Cerro Verde, the latter almost 3000 m in altitude. The range presents rounded crests covered by tree-like vegetation, particularly on the north facing sides. The slopes are covered with debris deposits, particularly thick and wide on the lower sides. The 23 explored caves are concentrated in the upper areas, above the altitude of 2600 m, mostly on low gradient surfaces close to mountain crests. For the most part they are non-active vertical caves, truncated by erosion and showing clear signs of senescence, as the altered stalactite and stalagmite deposits clearly demonstrate. The longest cave is Majada Somiate, at an altitude of 2300 m on the eastern slope of Cerro El Zotol, close to the small village of Mahujzapan. This cave consists of a 210 metres long and 20 metres wide gallery, filled by big stalagmites and speleothems deposits. The deepest cave is Pozo de los Murcielagos, a big system of interconnected pits that reach a depth of 85 metres where the bottom is completely closed by mud and guano (with the assured presence of the dangerous fungus *histoplasma capsulatum*). All the other vertical caves explored in this sector (MZ2 –37/50 m, CV4 –50/60 m, CV5 –60/70 m at an altitude of 2750 m) are filled to the bottom with mud and organic material and are completely dry. Only Cueva El Basulero, a sequence of narrow passages and short pits that opens other La Huerta springs, presents a small stream that flows in a very narrow meander not completely explored. Only in the lower plateau of Mauizapan some caves present a sensible "high entrance" air circulation, while in the higher slopes of Cerro Verde and Cerro Pericon caves have no air circulation and sometimes the presence of CO_2 due to the decomposition of organic material was found.

Right hydrographical highland

The highland located east of Juquila canyon represents the widest karst area and is characterised by flat areas, different from what may be found on the left hydrographical side, with several wide and shallow dolines and some collapse depressions. The 26 caves surveyed in this zone are concentrated in two areas: Cerro Grande, in the NW (CG zone), in the territory of Tepelmeme, surveyed in 2003, and Llano la Cumbre, in the SE (IX and TSA zone), in the territory of Santa Maria Ixcatlán, surveyed in 2006.

The longest and deepest cave is the Sotano de la Laguna Prieta (CG3) located near the top of Cerro Grande. The entrance consists of a wide collapse doline that opens on a 140 m deep shaft, formed by two joined parallel pits. A hanging terrace made of rock blocks opens on a 40 m vertical drop that gives origin to a high, few metres wide, gorge descending SE. A further 35 m deep pit leads into a chamber with big blocks embedded among the walls. The bottom section is definitely stuck by mud and organic material. The other relevant cave in Cerro Grande is the Pozo de la Vaca Ladra (CG4), not far from CG3; its entrance, also shaped as a collapse doline, leads into a 12 m deep pit. At its base a detritic slope leads onto a 100 m vertical drop, which consists of a pit with 4 x 6 metres elliptic plan. A narrow side passage, along the generating fracture of the pit, leads into a 7 m drop, closed by mud at the bottom.

Llano la Cumbre is a wide depression located NW of Santa Maria de Ixcatlán, artificially dammed in order to form a basin for watering livestock. The largest cave of this area is Sotano Rodeo (IX1); it opens with a 10 m large sinkhole. It is composed of three vertical pits of 40, 10 and 75 metres. At the bottom is a small meander, blocked by debris after about twenty metres at a depth of -135 m. For the main part, the other explored caves are in the small valleys of the Terrero San Antonio, 2-3 km north of Llano la Cumbre. Among these caves, the deepest one is Sotano la Calabera (TSA6) consisting of a single 77 m deep shaft.

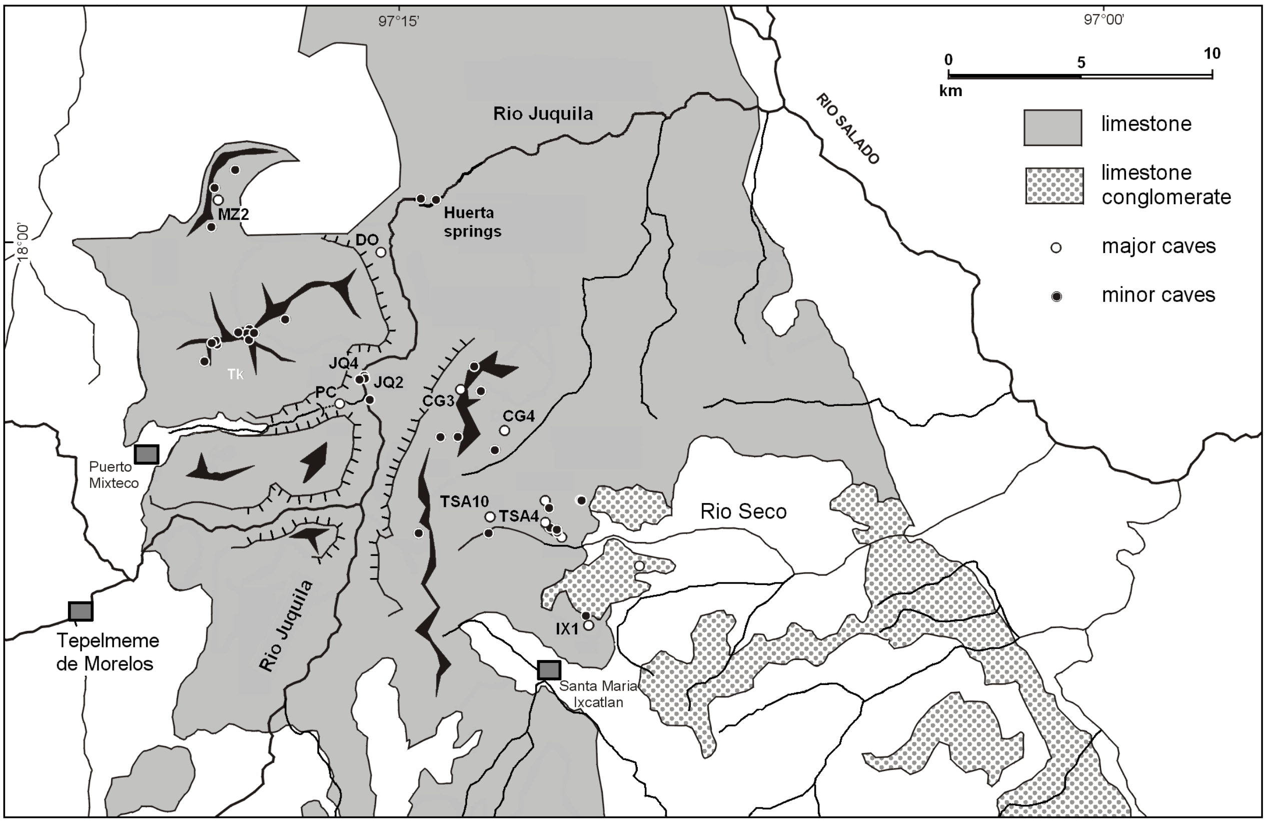

Fig. 7 – Sketch geological map of the karst area with the entrances of the main explored caves (cave labels are those in table 1).

The main valley is now divided into small blind basins, lined in N-S direction and drained by sinking streams. Probably, before the waters were absorbed underground, they formed a single valley, the left tributary of Rio Seco. At the present time, the runoff rills are active only in the wet season. Following the bottom of the ditches, two sinkholes were discovered and explored for a few tens of metres, Cueva Perfecto 3 (TSA15), upstream, and Sumidero San Antonio (TSA4), downstream. Cueva Perfecto 3 starts with a 20 m pit and continues in a gorge that after a dozen metres ends up in a chamber, where two different conduits may be covered for a maximum of 30 m both upstream and downstream. The latter shows a low gradient, meander-like course and ends up in a shallow water pool (-39 m). Along the same valley line, 700 m downstream TSA15, we find the second sinkhole, Sumidero San Antonio, 100 m long. This cave as well as Cueva el Calacote (TSA10), that opens 2 km further west, is particularly interesting for the understanding of the geological evolution of the area because these caves show solution forms typical of a convective circulation of thermal waters, with calcite crusts covering distinctive dome-shaped voids. This morphology might testify to an ancient phase of karstification produced by uprising hot water, and therefore the two caves might be among the oldest ones in the region. Presently, the surface erosion has exhumed the two caves and in Sumidero San Antonio the hydrothermal forms were locally remoulded by the flow of the rainwater stream sinking into it.

5. Conclusions

The evolution of caves and karst in the area of Juquila Canyon is certainly related to the complex morpho-tectonic history of the Tehuacán basin. The present relief represents what remains of an

ancient planned surface that might have formed in the late Cenozoic, during a period of relative tectonic quiescence. During the formation of this surface the karst should not be so developed in extension and depth. The opening of new fractures during the faulting events and the deepening of the canyon, forced the transfer of the flow through underground pathways, with the activation of springs located at lower altitudes. The change of the drainage network implied activating new fractures and widening them to form new caves (Piccini et al., 2008).
At the present time, we observe find several phase of karst development. The most ancient caves are located in the southern section of the studied area, and are hypogenic caves elaborated again by percolation waters and intercepted by surface erosion. Such caves might be related to the last phases of the Tertiary magmatic activity that affected the area (Miocene?).
Surface karst dissolution had a relevant role levelling the topographic surface. As a consequence, the first-phase karst forms have not survived, other than as relict and truncated caves. Traces of the progressive lowering of the base level are found in the canyon walls, mainly between 1600 and 1500 m a.s.l.; they are segments of an ancient phreatic network that fed springs deactivated due to the following lowering of the base level. Also the vertical caves explored on the highland may belong to different generations and some of them are still rather active, despite the scarcity of rain feeding the underground network. At present, the decrease in the feeding of the karst network, due to the recent passage to a drier climate, has reduced the entity of karst dissolution and slowed down the development of the underground network. Furthermore, the progressive washing away of the soils present on the top plateau together with the abundant vegetable material, is leading to the obstruction of the karst cavities. This seems to be one of the main reasons that have kept us from reaching the deeper parts of the karst systems.

Acknowledgements
The Juquila Project is sponsored in Italy by: Società Speleologica Italiana, Istituto Italiano di Speleologia, Club Alpino Italiano; in Mexico by: Aviacsa, Semarnat (Secretaría del Medio Ambiente y Recursos Naturales), Reserva de la Biosfera de Tehuacán-Cuicatlán.

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Table 1 – Location and dimensions of major explored caves.

Name (cave label)	UTM E (14) (NAD27)	UTM N (NAD27)	Altitude m a.s.l.	Vertical range m	Length m
Puente Colossal (PC)	683060	1984840	1760	- 37	255
Cueva Dos Ojos (DO)	684538	1990564	1495	-25, +30	1020
Cueva Espinosa (CE)	684672	1983010	1529	150	+15
Sotano de la Laguna Prieta (CG-3)	687555	1985460	2490	- 280	330
Pozo de la Vaca Ladra (CG-4)	688335	1985380	1495	-25, +30	1020
Sumidero San Antonio (TSA4)	690860	1980580	2190	-23	100
Sotano la Calavera (TSA6)	691435	1980020	2260	-77	100
Cueva Perfecto 3 (TSA15)	690775	1981275	2265	-39	172
Sotano Rodeo 1 (IX1)	692420	1976625	2200	-135	210