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Structural Control on Cave Development in Cretaceous Limestone, Southern Puerto Rico

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ABSTRACT.—Surveys of Sistema Los Chorros (815 m length) and Sistema Vientos (600 m) represent the first cave maps from southern Puerto Rico published in the last quarter century. These are the largest caves known in that area. They have developed at about 100 m asl in resistant Cretaceous limestones and display structural control dominated by strike and dip (35-60 °), as well as faults and clastic dikes. In profile they display 2-4 vertically- separated levels with slopes of 30-60 m/km, all greater than those of neighboring surface streams, and indicate relative groundwater lowering of 40-60 meters.

KEYWORDS.—karst, Puerto Rico, geomorphology, cave maps

Karst (a solutional landscape of *mogotes* and topographic depressions) is present in approximately 27% of Puerto Rico, and hosts the largest aquifers *(water-bearing rocks*) of the island. This karst surface and its hydrology has been studied for some decades (e.g., Monroe 1976; Giusti 1978), and most recently in the publication "*Puerto Rican Karst, a Vital Resource*" (Lugo et al. 2001). However, none of these large manuscripts contain a map of any cave on the island, although Monroe, op. cit., shows the Rio Camuy Caves as a line. Caves are that fraction of an aquifer porosity of sufficient size to be physically traversable for humans. The hydrologic significance of caves is that their diameter relative to mean porosity transmits substantial percentages of the total groundwater flow. In soluble materials such as limestones, the correlation of flow with solution of the host material creates a positive feedback that continually increases the importance of conduits as foci of internal aquifer discharge. This internal evolution of soluble aquifers ultimately makes caves the master controls of such flow, enlarging the extent of tributary contributions.

Caves in maturely-developed karsts and tectonically-active areas, such as Puerto Rico, usually have developed vertically-separated levels or galleries of similar slopes and elevation that represent saturated development at or near "water-tables," subsequently followed by abandonment and successive development at lower elevations (Miller 1996). Each cave level retains evidence of the past climate and species, drainage boundaries, direction and amount of water discharge, etc. at each age of development, in the form of internal deposits, fossils, and solutional features. Caves are superior locations of these data because they persist for hundreds of thousands of years protected from surface weathering environments.

Publication of cave maps will ultimately enhance the ability to predict the provenance and destination of modern flow in inaccessible portions of modern aquifers, as well as provide dateable snapshots of preceding environments, and timing and rates of past seismic activity. There is as yet no substitute for human access and detailed mapping by qualified cave surveyors for defining the three-dimensional space of caves and associated characteristics (sizes, orientation, relation to geologic strata, internal water bodies, sediments, deposits, and rock features) to provide data for interpreting the past geologic history of an aquifer.

Cartographic survey methods in caves consist of measuring the distance and directional vectors between a series of stations through a passage. A sketch of the passage dimensions is made simultaneously, and often accompanied by an inventory of geologic deposits, features and structure (e.g., strike and dip measured with a Brunton compass). The recorded data is then entered in a computer program and converted to digital x-y-z coordinates.

The physical difficulties of accessing caves, and traversing their constricted, flooded, or vertical segments, can limit survey to 20-100 m/h, irrespective of surface and subsurface travel to and from the survey site.

Individual cave maps, and diagramed hydrological systems in Puerto Rico, have been published in short papers and in graduate theses (e.g. Torres, Aguilar, and Pannela 1984; Troester 1994), but these have focused on small areas of the overall karst of the island, as have the few maps in these documents. Most published maps of Puerto Rico caves have appeared in publications for very specialized audiences (e.g. Courbon et al. 1989). Only two maps have been published of caves outside the main area of Puerto Rico's north coast (Beck 1974; and Beck, Fram, and Carvajal 1976) even though more than 10% of the island's karst occurs in these southern areas. Discussion of geologic controls was not the primary subject for either, and only the second was accompanied by a passage profile to graphically provide vertical data. These southern karsts differ from those of the north in often being developed on much older rocks (e.g. limestones of Cretaceous versus Tertiary age), and in drier climates. (Figure 1). Limestones in southern Puerto Rico are relatively resistant compared to neighboring lithologies, and commonly outcrop on the hilltops and ridges.

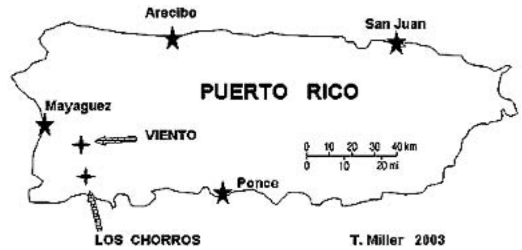

FIG. 1. Location of the Sistema Los Chorros and Sistema Vientos in southwestern Puerto Rico.

Surveys of Sistema Los Chorros and Sistema Vientos represent the first maps of southern Puerto Rican caves published in the last quarter century and enlarge information concerning groundwater location and tectonic uplift of the recent geologic past in this area. They were first described in print by Troester (1984), and both are located in Cretaceous limestones of Municipio San Germán.

Sistema Los Chorros (Figure 2) is the longer of the two, with 815 m surveyed. Its elevation range is 100-120 m in a resistant, ridge-forming, fault-bounded segment of the Cretaceous Cotui Limestone (Volckmann 1984, and Figure 3).

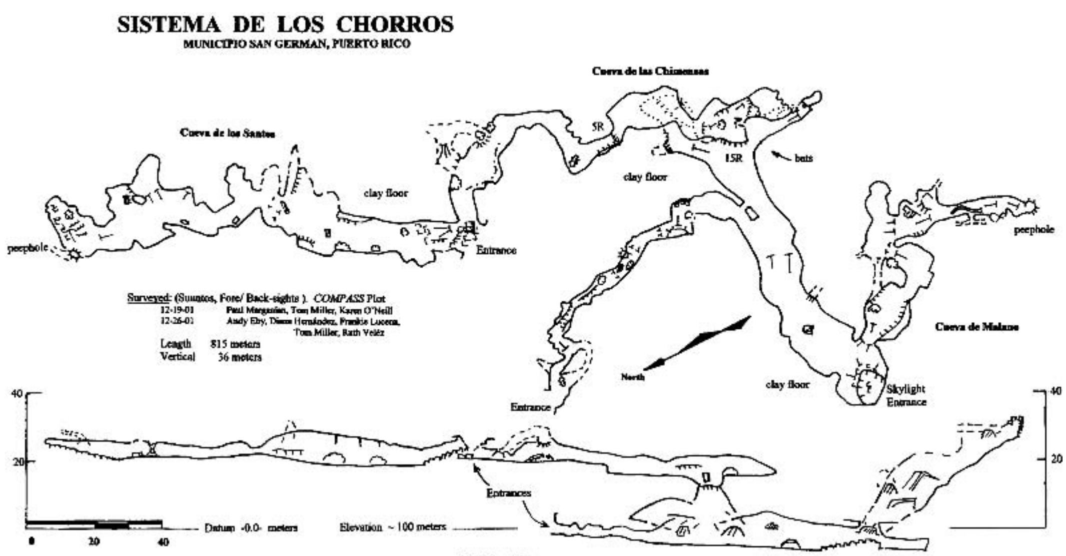

FIG. 2. Standard plan/profile cave map of Sistema Los Chorros, Municipio San Germán, Puerto Rico.

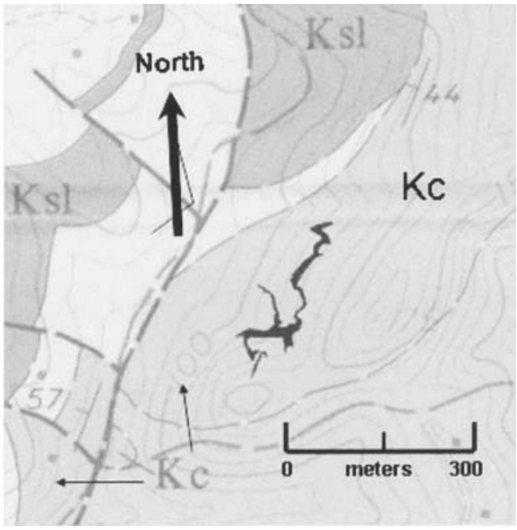

FIG. 3. Geologic map (Volckmann 1984) with overlay of Sistema Los Chorros. **Kc** is the Cotui Limestone unit; **Ksl** are limestone lenses of the Sabana Grande Formation; all other units shown are volcanic rocks in various stages of weathering.

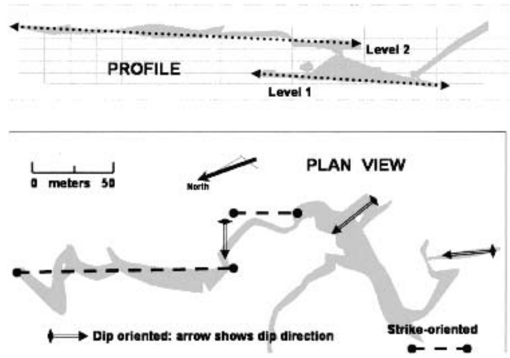

FIG. 4. Dimensional plan/profile map of Sistema Los Chorros. There is no vertical exaggeration of the scale, and the plan and profile are orthogonal to each other.

Figure 2 displays internal cave features represented by conventional symbols to a detail useful for a variety of disciplines (biology, archeology, etc.). Typically, a horizontal view of the cave from above (Plan View) is used to expose strata influences such as dip and strike, or major joints and faults. This is usefully paired with a vertical view of the cave from the side (Profile) to display the presence of more than one level, indicative of a relative vertical adjustment in the local "watertable," due either to tectonic uplift, or regional downward erosion by the master streams of the area. To aid a specific geologic interpretation, computer-generated passage dimensions may be imprinted with a reduced set of internal data on the plan and profile view, such as Los Chorros in Figure 4, although some passage detail is lost.

The internal topography of Los Chorros shows a complex horizontal pattern that is also developed in two vertically-separated levels. The levels reflect a long-term interval of adjustment to changes in local stream base-level. The topographic dip of both the upper level passage (30 m/km) and the lower level (41 m/km) are greater than the current dip of the neighboring surface stream of Quebrada de Los Llanos (25 m/km), reflecting re-adjustment from a past topography with a stream drainage system at least 60 meters higher. No streams currently flow through the cave, although most of the floors contain clays deposited during its intervals of subaqueous development. Internally, the horizontal orientation of passages is parallel either to the strike or dip, a geologic control common to many caves (strike is defined as being perpendicular to the dip of the strata). These upper level data are similar to that of the single nearby surface measurement reported as dipping 44 °NW (Volckmann op. cit.); orientation of some passages in the lower level strata differs significantly from this, probably due to local faulting.

The second cave, Sistema Vientos (Figure 5), ranges from 40-110 m elevation in a resistant ridge of the segmented Peñones Limestone (Cretaceous); at 600 m length, its survey is not yet complete. Strata dip measurements (37-60 °SW) reported on this unit (Curet 1986) were variable, and similar to those in neighboring portions of the cave (Figure 6).

Internally, Vientos' topography also displays a complex horizontal pattern, but developed with at least four vertically-separated levels (Figure 7) whose floors are surfaced (like those of Los Chorros) with clay deposited during its submerged development. The bottom level contains a small

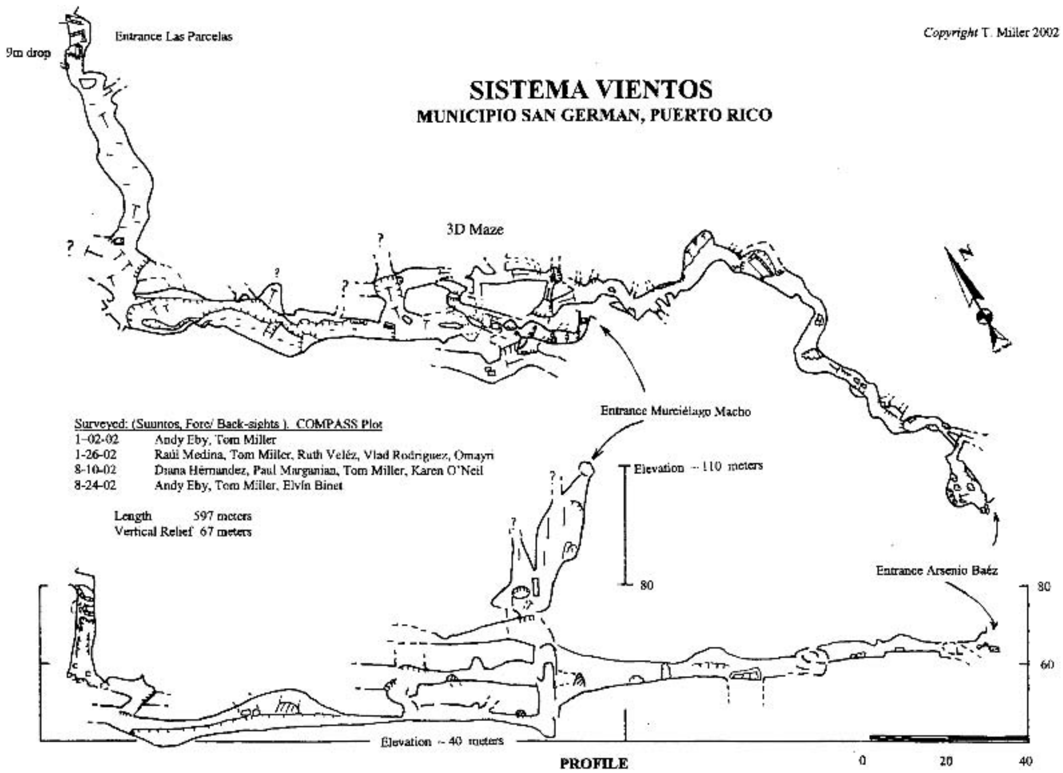

FIG. 5. Standard plan/profile cave map of Sistema Vientos, Municipio San Germán, Puerto Rico.

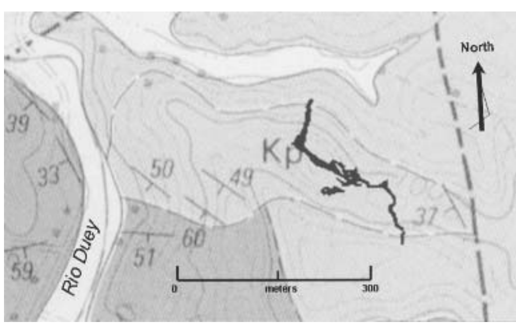

FIG. 6. Geologic map (Curet, 1986) with overlay of Sistema Vientos. **Kp** is the Peñones Limestone; all other units are non-carbonate rocks, or valley alluvium.

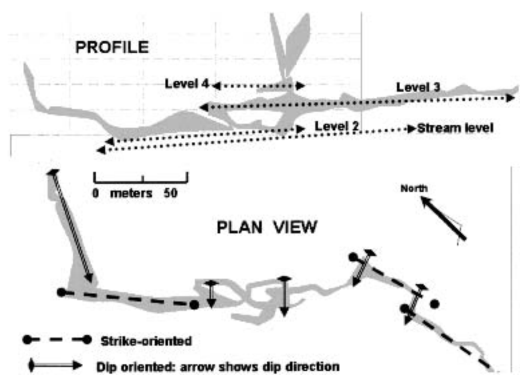

FIG. 7. Dimensional plan/profile map of Sistema Vientos. Strike and dip symbols are as in Fig 4.

active stream fed by a closed depression to the south from an ephemeral sinking stream; the stream exits to the west to Río Düey, tributary to Río Guanajibo drainage basin. The dip of the small stream is about 60 m/km, much greater than that of the outside Río Düey (10 m/km). As with Los Chorros, the upper, older, galleries also have lower gradients (e.g. Level 3, 45 m/km).

An unusual feature of this cave is at least ten vertical series of shafts and pits that pierce the horizontal levels from the surface; they indicate an active surface karst development phase that has coincidentally intersected the pre-existing cave of much greater age (still in adjustment from a previous stream drainage system perhaps 40 meters higher). The shafts usually follow small vertical faults and clastic dikes.

The horizontal orientations of Vientos' passages are also parallel either to the strike or dip (Figure 7), although there is considerably more internal variability than with Los Chorros. The internal strata incline generally at 30-60 °, with considerable horizontal shifting of the strike (up to 45 °) due to fault offsets.

In summary, the two caves share features common to other caves of the southern karsts of Puerto Rico: they have developed vertically-separated levels preserving evidence of relative groundwater lowering of 40-60 m, with passages dominantly guided by the dip and strike of the geologic strata. Additional cave maps from southern Puerto Rico will be published as those surveys are completed, including more-detailed internal structural data.

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