

# Speleogenesis of juvenile serial sinkhole-resurgence systems in the karsts of the Amazonian side of the Andes Mountains, Peru

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## Abstract

Serial sinkhole-resurgence systems, crossed by the river, are frequent in Northern Peru. We present here two examples from the Amazonas region, located in the karsts of Cerro Shipago (Utcubamba Prov.) and Soloco (Chachapoyas Prov.). The rivers flowing on the topographical surface sink underground rapidly in less than 10 km distance. The underground segments develop alternatively along dip or joints. They systematically remain at shallow depth. These series of sinkhole-resurgence systems are typical of mountains with high uplift rate and under a wet climate regime. Such karst features correspond to juvenile systems that appear during the first karstification phase of the limestone. Surface runoff occurring on low-permeability covers are gradually captured by sinkholes. Beyond the geological structure, the evolution of these sinkhole-resurgence systems is mainly controlled by surficial dynamic, especially the thickness of low-permeability covers, the topographic gradient and the incision dynamic of the valleys.

## Résumé

**Spéléogénèse des systèmes juvéniles de type doline-résurgence en série, dans les karsts de la face amazonienne de la Cordillère des Andes, Pérou.** Les systèmes perte-résurgence en série, traversés par une même rivière, sont fréquents dans le nord du Pérou. Deux exemples dans la région d'Amazonas sont présentés, situés dans les karsts de Cerro Shipago (Prov. d'Utcubamba) et de Soloco (Prov. de Chachapoyas). Les rivières se perdent parfois jusqu'à trois fois sous terre en seulement 10 km de distance. Les tronçons souterrains se développent tantôt selon le pendage, tantôt selon la fracturation. Dans tous les cas, ces tronçons restent à proximité de la surface, sans pénétration à grande profondeur. Ces systèmes perte-résurgence en série sont typiques des hautes montagnes en forte surrection, bénéficiant de précipitations importantes. Ils correspondent à des réseaux juvéniles apparaissant avec la première karstification d'ensemble des calcaires. Les écoulements de surface soutenus par la présence de couvertures imperméables sont progressivement capturés par des pertes. Au-delà de la structure géologique, l'évolution des systèmes juvéniles de perte-résurgence en série est contrôlée principalement par la dynamique de surface, notamment l'épaisseur des couvertures imperméables, le gradient topographique et la dynamique d'incision des vallées.

## Resumen

**Espeleogénesis de sistemas juveniles de sumidero-resurgimiento, en los karts de la vertiente amazónica de la Cordillera de los Andes, Perú.** Los sistemas de pérdida-resurgencia en serie, cruzados por el mismo río, son comunes en el norte de Perú. Se presentan dos ejemplos en la región Amazonas, ubicados en los karsts de Cerro Shipago (Prov. de Utcubamba) y Soloco (Prov. de Chachapoyas). Los ríos a veces se pierden hasta tres veces bajo tierra en solo 10 km. Los tramos subterráneos se desarrollan a veces según el buzamiento, a veces según la fractura. En todos los casos, estos tramos permanecen próximos a la superficie, sin penetrar a gran profundidad. Estos sistemas de pérdida-resurgencia en serie son típicos de las altas montañas, que se benefician de precipitaciones importantes. Corresponden a redes juveniles que aparecen con la primera karstificación de todas las calizas. Los flujos superficiales, apoyados por la presencia de cubiertas impermeables, son capturados gradualmente por las pérdidas. Más allá de la estructura geológica, la evolución de los sistemas juveniles de pérdida-resurgencia en serie está controlada principalmente por la dinámica de la superficie, incluido la potencia de las cubiertas impermeables, el gradiente topográfico y la dinámica de la incisión del valle.

## 1. Introduction

Since 2003, the ECA club of Lima (Espeleo-club Andino) and French caving clubs, such as the Bagnols-Marcoule Speleological Group (GSBM), have been exploring continuously the karsts of Northern Peru. During numerous explorations in the Amazonian foothills of the Andes, the frequency of sinkhole-resurgence systems led us to look for the reasons behind the origin of the concentration of such karst phenomena in this area.

## 2. The slopes of Cerro Shipago

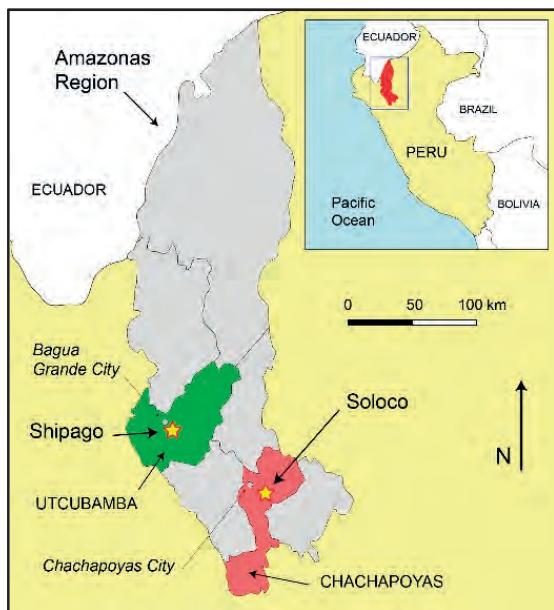


Figure 1: Location of the two provinces of Amazonas Region (Peru) and the sinkhole-resurgence systems of Cerro Shipago (Utcubamba) and Soloco (Chachapoyas).

### a) Geological context

Cerro Shipago is one of the highest points (alt. 2849 m) of the limestone massif which extends to the south of the Bagua Grande city, in the Utcubamba Province. The Shipago massif appears as a large anticline fold, with a Permian sandstones core. It is capped by cretaceous series, including limestones, which form a monocline cover on the northern slope of the massif, from its summit to the bottom of the Bagua-Utcubamba syncline valley (alt. 430 m). The cretaceous formation, of several hundred meters thick, displays a steep dip to the north.

The massif is extensively karstified at high altitudes where higher rainfalls are more frequent. Indeed, the longest caves are located above 2000 m. The hilly topography rarely

Are the series of sinkhole-resurgence systems a main characteristic of the Andino-Amazonian karsts of Peru?

We describe here two examples in the Amazonas Region (Fig. 1), the karsts of Cerro Shipago (Utcubamba) and the massif of Soloco (Chachapoyas), in order to identify similar features and that may provide an explanation for the frequency of these sinkhole-resurgence systems.

reveals the limestone outcrops, which is covered by thick weathering layers. However, sinkholes (locally called *tragaderos*) capture the streams at the bottom of closed sinks, making the caves active and crossed by streams (Fig. 2).

### b) The series of sinkhole-resurgence system of the Río de las Tres Naranjas

The Tragadero del Río de las Tres Naranjas (alt. 2470 m) shows a complete set of passages forming a series of sinkhole-resurgence system of about 250 m in length each (BIGOT, 2019). The system has active and non-active passages over 739 m long and 17 m vertical range.

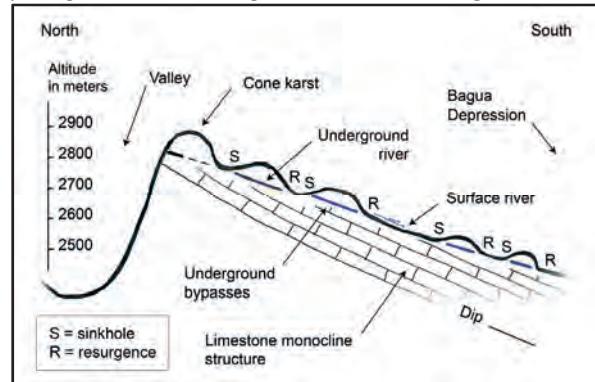


Figure 2: Schematic profile of the Shipago massif showing the shallow development of cave passages as a series of sinkhole-resurgence systems

Such caves are typical contact caves, developed along the dip, following a thin marly layer interbedded in Cretaceous limestones and locally guided by vertical fractures. These sinkhole-resurgence systems do not penetrate deep into the thick limestone and remain at shallow depth, below a thin layer of limestone. These karst systems are probably young, because they are still active.

## 3. The Soloco area

### a) A series of sinkhole-resurgence systems in Soloco area

The series of sinkhole-resurgence systems in this area are extending over a distance of approximately 10 km, from the heights of Ancayrumo down to the Sonche valley (Fig. 3).

From upstream to downstream, segments are: Ancayrumo-Yacuñahui River, Chaquil-Río Seco, and Salcaquihua River-El Molino. Río Seco Cave is the main segment, with 2095 m long and 42 m vertical range (-20, +22).

The nearby resurgence of the Río Seco is the largest in the area with an average discharge of about  $1.2 \text{ m}^3/\text{s}$  and a catchment area of about  $40 \text{ km}^2$  (GUYOT, 2006). The system is probably fed by the river that sinks into the Tragadero de Chaquil (alt. 2986 m), located 300 m higher and 2.6 km upstream to the south.

Another underground system is developing parallel to Chaquil and Río Seco: the sinkholes of Parjugsha Grande, Parjugsha Alto, and Vaca Negra (Fig. 4). Underground segments were previously partly explored.

#### b) Hydrogeological and geomorphological context

Caves are developing in the Chambara Fm. limestone of Upper Triassic (BABY, 2006).

The general structure corresponds to a succession of thick limestone stripes between impermeable clastic formations. Sinkholes and resurgences are located at the contact of these formations. As a consequence, the three sinkhole-resurgence systems do not have direct morphological link, apart from the stream that crosses them.

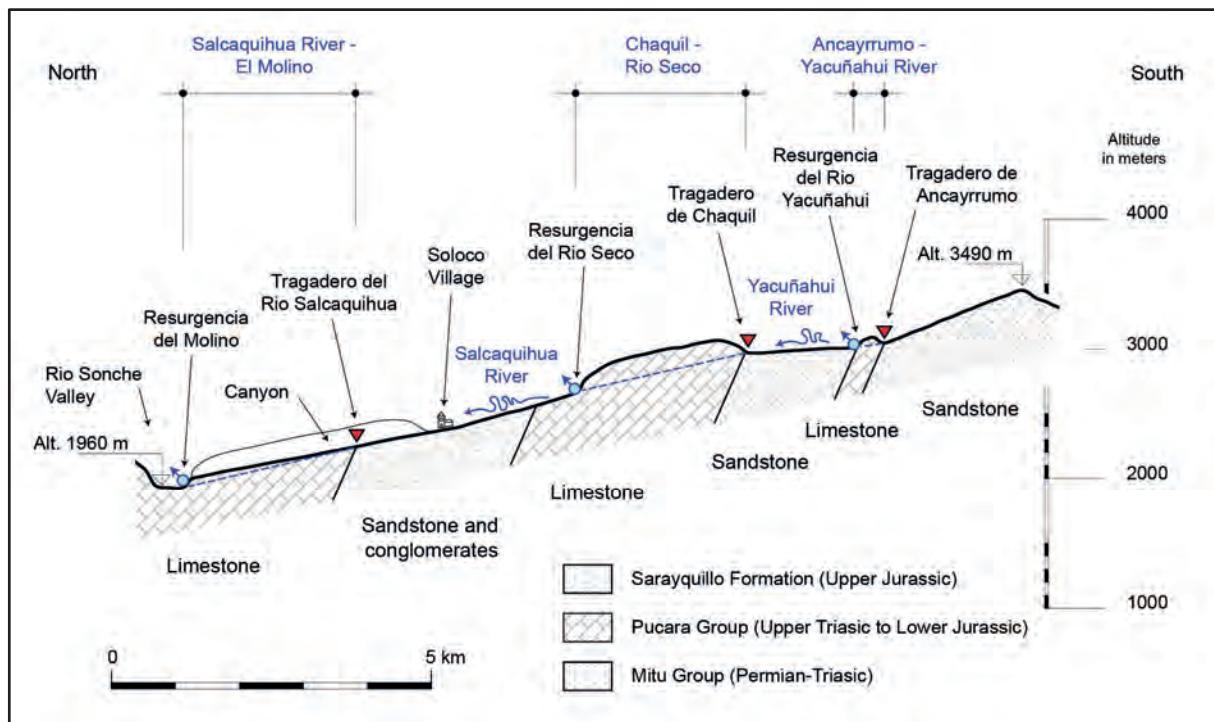


Figure 3: Schematic profile along the series of sinkhole-resurgence systems in the Soloco area. The details of the complex tectonic at the origin of the succession of stripes of the same limestone has not been indicated.

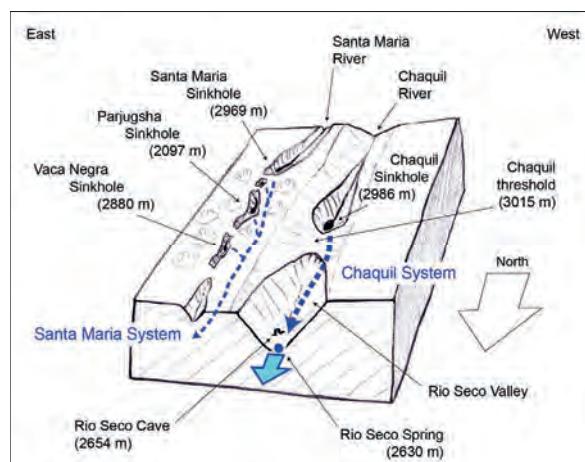


Figure 4: Simplified block diagram of the Soloco massif showing the two parallel underground systems.

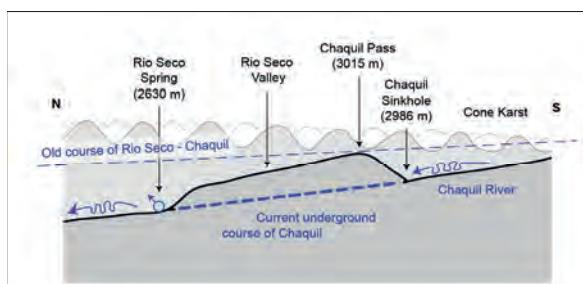


Figure 5: Simplified longitudinal profile of the Río Seco. The pass located at 3015 m attests to the ancient valley of Chaquil whose course has become underground.

The geomorphology of the massif shows that the surface river of Chaquil previously flowed in the Río Seco valley (Fig. 5). The underground captures gradually drained the valley, leaving a threshold upstream, which corresponds to the Chaquil pass (BIGOT, 2013).

## 4. Discussion and conclusion

In this area of Andino-Amazonia of Northern Peru, most of the caves are characterized by segments of underground bypasses, organized as a series of sinkholes-resurgences along the course of surficial rivers. Some cave waters of streams are crossing limestone stripes and reappear when arriving at the contact of impervious rocks (Soloco area). Others show the same trend even when crossing entirely limestone rocks (Cerro Shipago). In the latter, the cave systems are also guided by a thin marly inception horizon. Here, the underground segments are located along the dip of the limestone strata, locally guided by joints of similar direction as the general gradient. In all the explored caves, caves remain generally at shallow depth below the cone karst landscape. It seems that cave systems with vertical shafts are absent in this area, in opposite to the classical "alpine caves" model, whose caves reach great depth by using succession of fractures (AUDRA et al., 2002).

Such pattern of speleogenesis is typical of the juvenile cave type (AUDRA & PALMER, 2015). It is characteristic of recent karst areas with very fast uplift rates, conducting to important hilly landscapes and significantly eroded under a wet tropical climate such the case of the Amazonian side of the Andean Chain.

Consequently, the hypothesized story behind the karstification, since its early stage to the present-time as seen in both examples here-above, begin with a buried deep limestone which was initially not karstified.

As a consequence, before outcropping, the limestone masses were not karstified, being buried at great depth. This observation is supported by the high runoff largely present at the surface and still eroding or draining the thick

weathering covers. Then caves begin to develop from the concentrated input of the streams. Caves follow prominent discontinuities, mainly bedding planes especially when inception horizons are present, fractures parallel to the slope, along the shortest path from sinkhole to resurgence. The resulting pattern shows a rectilinear plan with a moderate and constant slope from sinkhole to resurgence. Caves are always active whereas, abandoned passages are limited to some loops located at a moderate height above the active stream referring thus to their recent abandonment by the drainage system.

In some areas (Soloco), it is possible to follow the evolution stages, from shallow surface valley in the cone karst landscape, to progressive captures in underground segments, then to additional captures toward a new series of sinkhole-resurgence systems, whereas the first series of sinkhole-resurgence gradually tends toward an evolved landscape with large doline fields (Fig. 3, 5).

The new stream captures by sinkhole-resurgence systems are controlled by the dynamic of surface rivers, where those with the largest incision rate are gradually capturing the neighbouring catchment areas.

Finally, we conclude that the early development of underground karst conduits is initially controlled by the landscape characteristics and dynamic: i) the distribution, thickness, and evolution of the weathering covers controls the location of first sinkholes; ii) the topographic gradient controls the slope and extension of juvenile cave systems; iii) the large catchment areas produce surface rivers with higher incision rates that gradually capture the neighbouring catchment areas.

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- The Peruvian cave files with topographies are available on the website <http://www.cuevaselperu.org>
- All topographic data and drawings for *TheRion* are available at  
[https://github.com/robertxa/Mapas\\_Cavernas\\_Peru](https://github.com/robertxa/Mapas_Cavernas_Peru)