GEOCHEMISTRY OF SURFACE AND CAVE WATERS IN THE TEPUIS QUARTZITE PLATEAUS (VENEZUELA)

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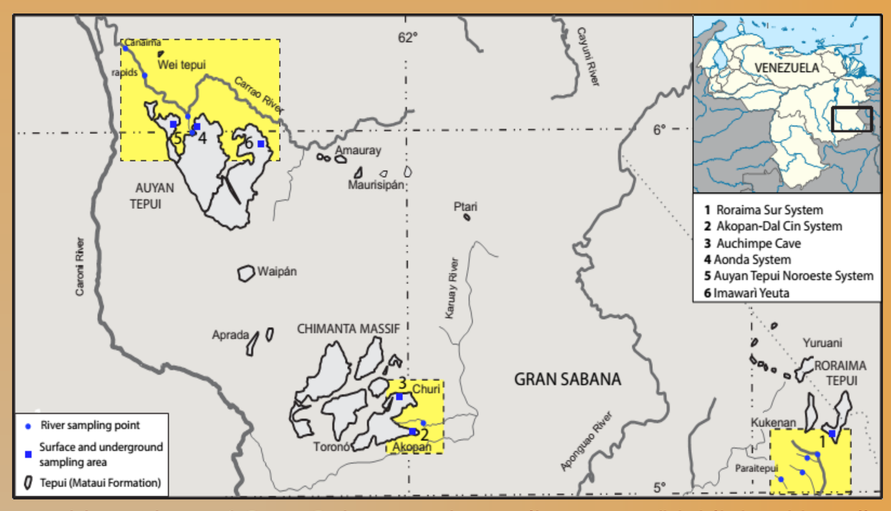
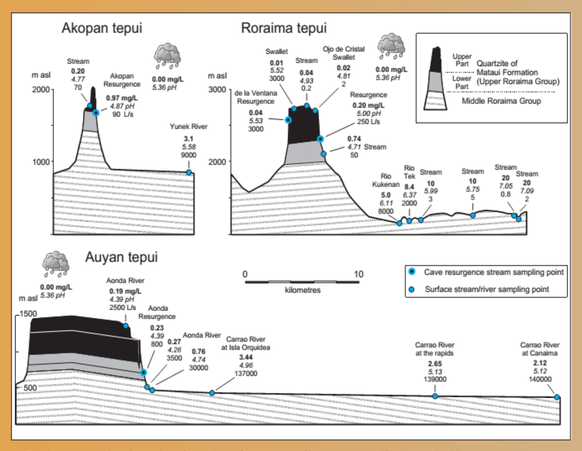
Quartzite and quartz-rich sandstones are among the less soluble rocks on Earth. Despite this, some areas in the world exhibit typical karst-like surface landforms and subterranean conduits being an evident result of surface and subsurface weathering. The resulting landscape has many features in common with karst regions, leading many authors to classify the dominant geomorphic process as karst, although the dissolution has probably only a minor role, from a quantitative point of view. These karst-like landforms have been attributed to processes such as weathering (arenisation) and hydrothermal activity, or to a simple diagenetic predisposition of the hostrock.

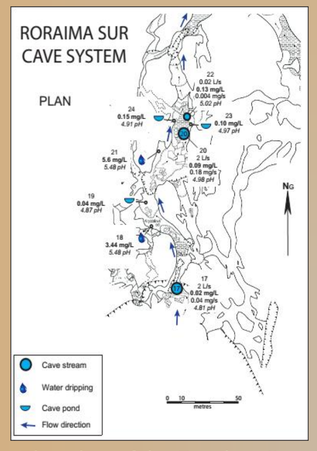
An underground drainage in quartz-arenites implies a process of deep weathering along fractures without production of secondary minerals, such as clay minerals, that might clogg the fractures and inhibit the water flow. This means that, at least in the first phases of speleogenesis, the weathering has to act mainly in pure-quartz layers by solution of quartz and leading successively to the genesis of voids and conduits by mechanic removal of decemented sand (piping). For this reason the dissolution of silica is a key-factor to understand the process that leads to such a particular landscape.



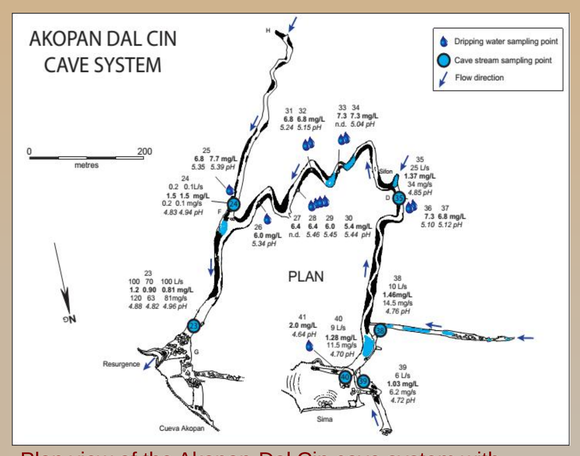
Geographic settings of Gran Sabana and sampling areas (highlighted in yellow).



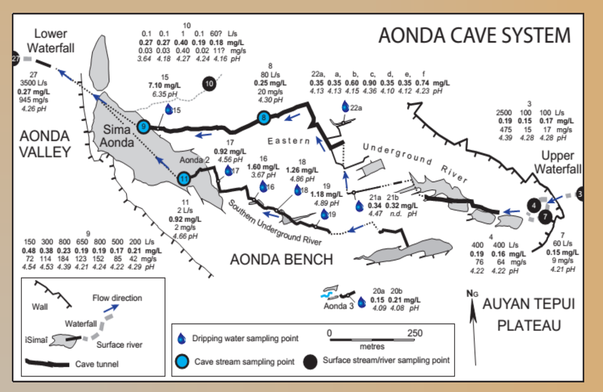
Schematic hydrological sampling profiles of Akopan, Roraima and Auyan tepuis. The numbers in bold refer to silica content, the pH values are indicated in italics, discharge is reported in litres per second. Rainfall values are below cloud symbol.



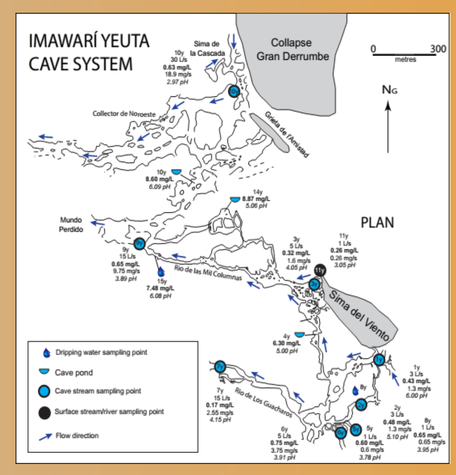
Plan view of the Roraima Sur cave system with sampling points and analytic results. The numbers in bold refer to silica content in mg L^{-1} of SiO_2, while dissolved load is expressed in mg s^{-1}; the pH values are indicated in italics; discharge is reported in litres per second (Survey from Brewer-Carias and Audy, 2011).



Plan view of the Akopan-Dal Cin cave system with sampling points and analytic results. The numbers in bold refer to silica content in mg L^{-1} of SiO_2, while dissolved load is expressed in mg s^{-1}; the pH values are indicated in italics; discharge is reported in litres per second.



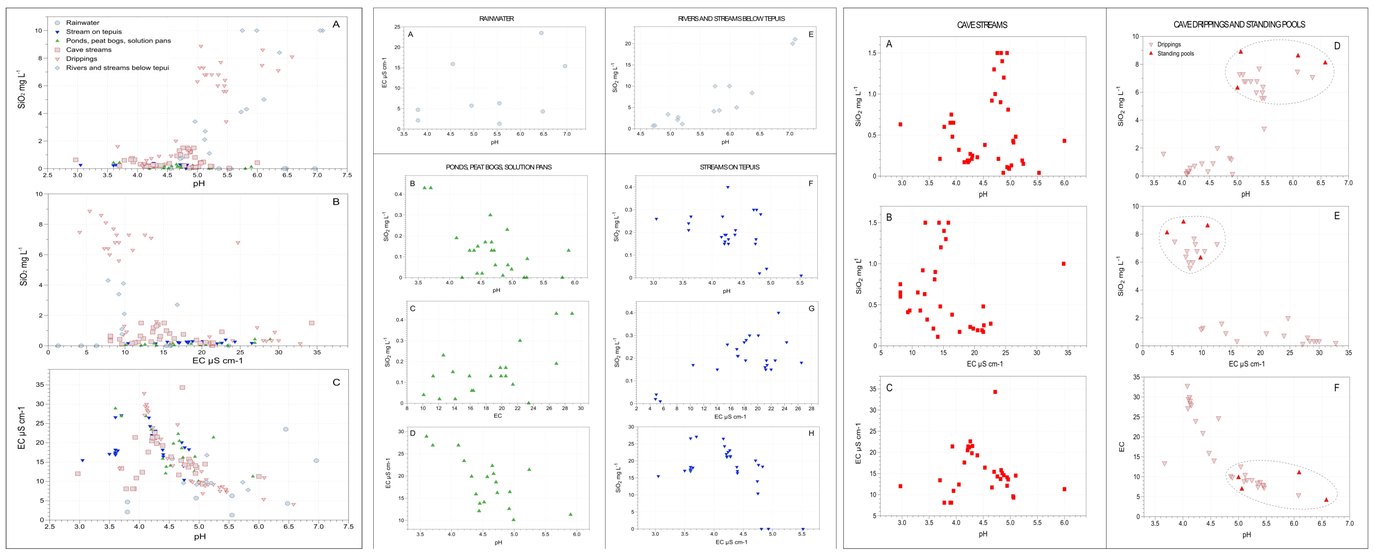
Plan view and hydrological scheme of the Aonda cave system showing the main rivers, sinkholes and resurgences. Sampling points and analytic results at different conditions of discharge are reported. The numbers in bold refer to silica content in mg L^{-1} of SiO_2, while dissolved load is expressed in mg s^{-1}; the pH values are indicated in italics; discharge is reported in litres per second.



Plan view of Imawarì Yeuta cave system with sampling points and analytic results. The numbers in bold refer to silica content in mg L^{-1} of SiO_2, while dissolved load is expressed in mg s^{-1}; the pH values are indicated in italics; discharge is reported in litres per second.

More than 150 chemical field analyses of waters, focused on the SiO_2 dissolution in surface and cave waters of three tepuis (Auyan, Roraima and Chimantha), have been carried out and the results have been compared with experimental studies. All these measures refer to the dry season, when the discharge of streams is lower than during the rainy season.

All the analysed waters are significantly under-saturated with respect to silica, except for those forming opal dripstones. The data show that about 15% of the silica load comes from surface weathering while 85% comes from underground solution.



Results for the whole set of samples analyses reported as correlations between SiO_2 concentration (mg L^{-1}), pH and EC (uS cm^{-1}). The different hydrological settings for each sample are reported in the legend. In A and B the extreme values of SiO_2 concentration up to 20 mg L^{-1} for the river below tepuis are not reported in order to have a better visualization of the dataset.

Correlation of the main physical parameters for the surface water samples. A) Rainwaters reported as pH-EC relation graph (no graph is required for the SiO_2 concentration because always below the detection limit). B-C-D) Relationships between SiO_2 concentration, pH and EC in ponds, peat bogs and solution pans samples. E) Dissolved silica versus pH in samples from rivers and stream below tepuis. Unfortunately the dataset of EC for these samples is incomplete and therefore is not reported as a graph. F-G-H) Relationships between SiO_2 concentration, pH and EC in streams on the tepui plateaus.

Correlation of the main physical parameters for the cave waters samples. DSi (SiO_2 mg L^{-1}) versus pH and EC (uS cm^{-1}) in cave streams (A-B-C) and in cave drips and standing pools (D-E-F). The dashed line highlights the high silica drippings and standing pools.

Different hydrodynamic conditions characterising the set of samples: A) Peat bogs and ponds on the tepui surface (photo La Venta). B) Stream on the tepui plateaus surface (Akopan Tepui) (photo Corrado Conca). C) The characteristic amber colour of cave streams in Imawarì Yeuta cave system (photo Vittorio Crobu). D) Crystal-clear water in standing pools fed by drippings in the fossil branches of Imawarì Yeuta (photo Vittorio Crobu). E) Waterfalls falling from the external cliffs of Chimanta Tepui (photo Vittorio Crobu). F) The Kukenan river at the base of Roraima Tepui (photo Vittorio Crobu).

Even if the detected concentrations of SiO_2 are low, quartz dissolution appears to play a fundamental role in the formation of the tepui landscape. The geochemical data show that the majority of dissolved silica in surface and underground waters of tepuis results from the dissolution of quartz while hydrolysis plays only a minor role.

On the top surface of the tepuis the dissolution of silica is very slow contributing only for 5-13% of the total dissolved silica load. In the subsurface the major contribution of silica to the underground drainage, about 87-95% of the total dissolved silica load, is most likely given by slow percolation along vertical fissures and horizontal interstrata or laminar movements of condensed water films on cave walls. These waters could be enriched in SiO_2 not only from direct dissolution but mainly by chemical potential diffusion from the intergranular porosity-saturated waters.

The low content of K, Al, and Fe documented in some samples are probably related to local hydrolysis, dissolution of minor kaolinite and goethite in certain layers. All these chemical data suggest that arenisation sensu Jennings (1983) is an active process.

In conclusion, weathering on the tepui table mountains works mainly underground causing the opening of deep fractures (grietas) and the formation of extended horizontal conduit networks. The tepui top surface is lowering mostly through collapses related to these underground processes, while scarp retreat is controlled by the higher weathering rate of the more arkosic formations constituting the base of the massifs.