Karst and Caves of Atiu – Cook Islands

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This article provides a basic overview of the recent research work undertaken on Atiu, in the Cook Islands Archipelago, its geology and caves.

During October 2018, a two-week research expedition was undertaken in the caves on the island of Atiu, in the Southern Islands group of the Cook Islands, to gain an understanding of what drives rainfall in this part of the world by interrogating past climate records. The field trip to the caves in Atiu was part of the Australian Research Council (ARC) Discovery project 'South Pacific and Australian hydroclimatic history recorded by stalagmite calcite fabrics', which approaches the story of past climate by using annually stacked crystals in cave formations. Silvia, Andrea and John are the Australian leading team, joined by their PhD student Mohammadali Faraji. Adam Hartland is the New Zealand colleague, keen on looking at the nature of cave waters, and finally, I have been involved in my role of cave surveying and photography.

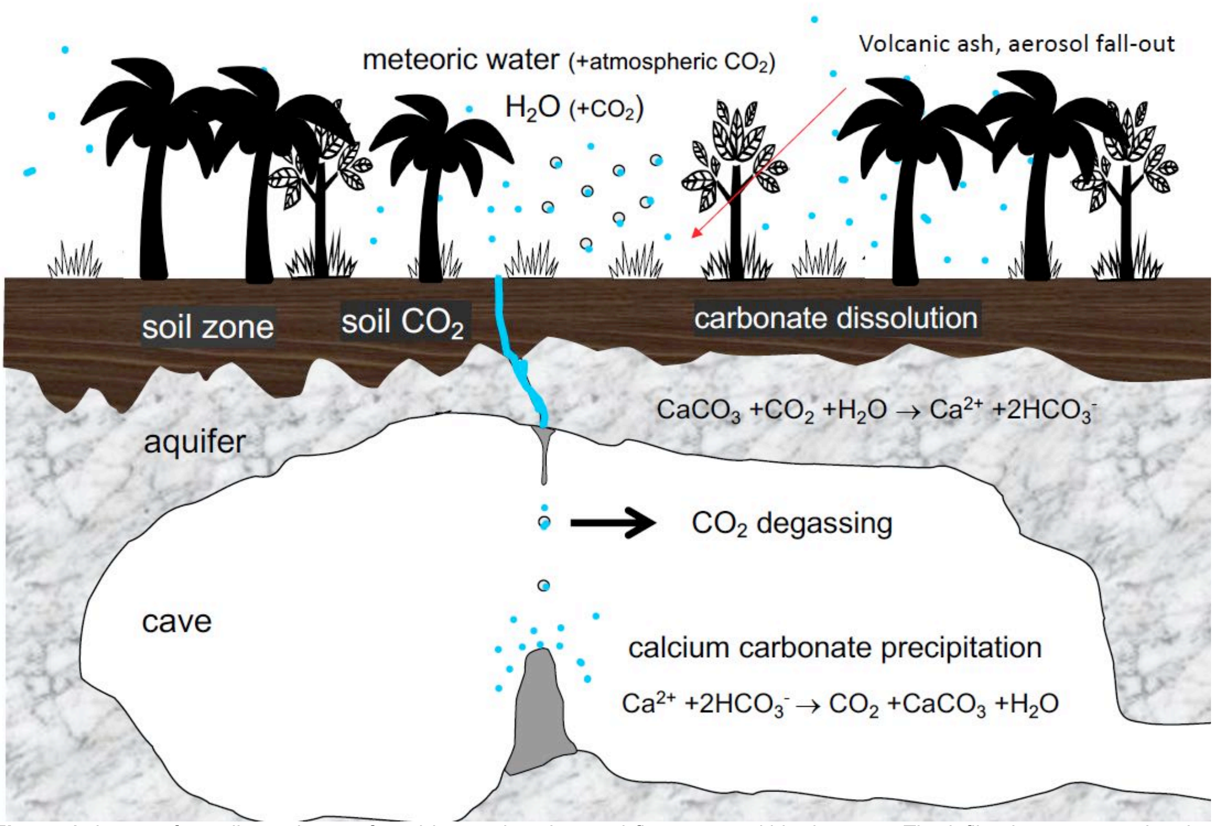


Figure 1: how surface climate is transferred into stalagmites and flowstones within the cave. The infiltration water carries the signals of the rain in its oxygen atoms (in the form of O isotope ratios). This signal changes according to how much it rains. The rainwater percolates through the soil, where it picks up CO_2 from roots and microbial respiration. The C now dissolved in the water carries the signal of the soil and its variability is related to the more efficient respiration (or less efficient) that occurs when it is wet (or dry). The infiltrating water also takes up some trace elements from the soil, for example Fe, or S from volcanic ash, or P from plants or even the marine aerosol. The infiltration water plus CO_2 has become a weak acid that dissolves the limestone and picks up calcium and a little bit of magnesium and strontium. Finally, the water enters the cave, releases the CO_2 to the cave atmosphere and is ready to form calcite containing all the signals from the surface. Those from the rock give us an idea of how long the water remains in the limestone, which is longer when it is dry. The dry period cave water will have more strontium and magnesium than the wet period water. So, we have plenty of cross-related information to find out how much it rained in the past (Adapted from Frisia & Borsato, 2010)

The research work looked at stalagmites and flowstones as reliable gauges of past variations in annual rainfall patterns. Trends and cycles, may be due to specific causes, such as changes in temperature of the ocean surface, or to small changes in energy from the sun, or even unknown behaviour of clouds. Stalagmites and flowstone have become one of the most important archives of rainfall changes, because they are directly related to rainfall via the water that infiltrates into the cave, which carries with it the signals from the atmosphere (Figure 1).

Our work in Atiu has the final goal of understanding changes in a band of clouds called the South Pacific Convergence Zone which brings rainfall to the South Pacific Nations. This band of clouds can be shifted to the north or south and changes shape when effected by another important band of clouds, the Intertropical Convergence Zone, which influences rainfall in Australia. Thus, what happens in Atiu has consequences also for us. That is because Earth's climate is complex and all is connected through the atmosphere and the oceans.

There were three caves of special interest, which had been identified three years earlier by Andrea and Silvia. The focus of the 2018 trip was to explore, survey and collect calcite deposits formed on previously placed drip stations. Our researchers wanted to study the crystals formed during wet and dry periods, monitor cave physics and water chemistry. This monitoring is fundamental for cave scientists to interpret stalagmite annual hydroclimate records.

The weathering rate of the karst was also of interest to the researchers, because little is known about the age of the karst and the caves. Thus, we collected relict samples of ancient stalagmites and flowstones occurring today on the surface of the limestone (paleokarst).

The caves on the islands have been known to the first human inhabitants since shortly after their arrival by canoe, believed to be around the 14th century. The arrival of intrepid Polynesian sailors with families, domesticated pigs and taro is evident because of the marae (sacred meeting site structures) they built out of stalagmites and columns extracted from the caves and used to mark the perimeter of the structure. The space between columns, which were laid down horizontally on the ground, was filled with white sand from the beach. Tools fashioned from basalt, which is much harder than limestone, were used to mine the speleothems.

The first recorded European to arrive at Atiu was Captain Cook, who sighted the island on 31st March 1777. Two of his crew eventually landed at a small beach called Ora Varu (Captain Cook's Landing), after being coaxed ashore by the islanders. In 1821 missionaries from the London Missionary Society began to work in the Cook Islands and the coastal dwellings were abandoned for villages higher up on the ancient volcano, where they are now. Some marae still marked by stalagmites and columns can be seen in the modern villages.

Today there are 5 villages that have merged to form one at the top of the island plateau. Roads and tracks radiate out from the hilltop and join a ring road, which follows the coastline. The whole island can be easily circumnavigated in an hour by motorbike and there are plenty of interesting things to stop and take in along the way. These include the wharf, harbour, Cook's Landing, coconut groves, marae sites and several churches.

During our research field trip we stayed at the well appointed Atiu Villas, which afforded the comforts of home and proved to be very convenient for day excursions to the various caves around the island and the coast. It must be pointed out that the caves are all located on local owner's land and special permission had been obtained from the Council of Atiu and landowners in order to visit them. Tourists can visit just a few caves. The most interesting is Anatakitaki Cave that is the home of an endemic species of the swift family, the rare kopeka bird.

Another cave visited for leisure is Vai Araruku Cave and its plunge pool, in which the water level rises and falls several cm with the ocean tides. During our visits we noted a large eel, some fish and crabs in the deep body of water in this cave. Obviously there are connections to the ocean, but not large enough to allow a free flow of tidal water to fully influence the cave water height, but large enough to allow marine creatures to enter and adapt to the brackish waters.

Karst and Caves in Atiu are of significance in that they tell us about past climate, provided construction material for early inhabitants and are home to unique fauna. The existence of these caves is due to the geological history of this island.

Geology of Atiu and the makatea

Atiu is a small island, roughly oval and measuring approximately 4.5 x 3 kilometres. The centre of the island is a flat topped plateau (70m ASL) formed by weathering and erosion of an ancient volcano. The volcano is rimmed by a raised coral reef about 1.6 km wide separated from the volcanic hill by a moat, now occupied by wetlands and a lake. This fossilised reef is known as *makatea* and has been dated to the Pleistocene, but the limestone may be much older, as the age of the volcanic island may be as old as 5 million years (Dickinson, 1998). The limestone (makatea) represents ancient, uplifted fringing reefs that now form girdles around the volcanic core of the island. These girdles have diverse heights, which reflect a very complicated story of global sea level changes, and local sea level variability related to the bulging of the lithosphere associated with the birth of the Rarotonga volcano (Dickinson, 1998). The youngest makatea forms a cliff in excess of 6 metres towering above the present lagoons, which are protected from the energy of the ocean waves (generated by the South Pacific) by fringing reefs. (Figure 2).

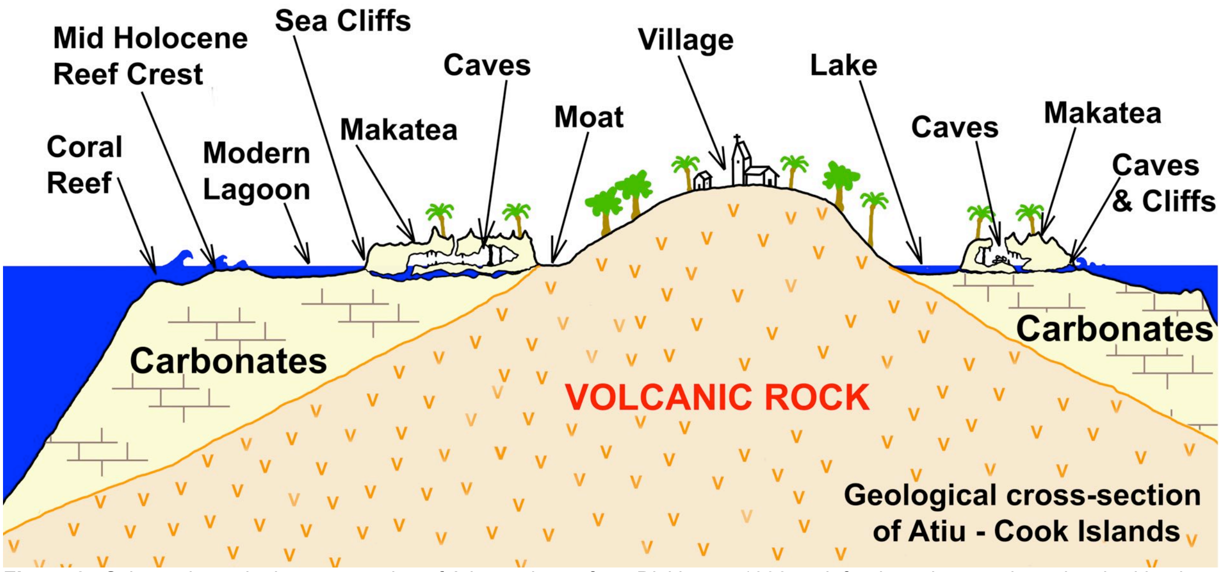


Figure 2. Schematic geologic cross section of Atiu, re-drawn from Dickinson, 1998 and, for the submerged part inspired by the work of Mylroie and Mylroie, (2007). The modern reef was added after observations conducted by Frisia & Borsato in October 2010 and 2019.

There are many swamps located in the contact zone between the island's central volcanic cone and the limestone. They form a natural freshwater storage area which gradually percolates through the aquifers into the water table of the makatea, thus reducing the ingress of salt water from the ocean.

The makatea has a jagged, pitted surface cross-cut by irregular karren, which results in razor sharp features. Any slip when crossing it could result in serious injury, including broken bones and deep cuts, which can quickly become infected in the high tropical humidity. This morphological aspect is well known for the coastal environment of tropical carbonate islands (Folk *et al.* 1973). Folk *et al* (1973) ascribed the razor sharp and pitted surface of tropical island karren to marine spray, boring endolithic algae, and grazing by gastropods.

Skylight #4, Pou Atea Cave, Atiu Island, Cook Islands. Photo by Garry K. Smith

Subsequently, Taborosˇi *et al.* (2004) demonstrated that the key factor for the evolution of a jugged karst surface was the lack of diagenetic maturity of the rock. Diagenesis is the process that changes a sediment into a rock through compaction and cementation. In the case of carbonates, much of the cementation is by other carbonate, which is released by the dissolution of the original carbonate minerals. This etching of the makatea is typical of young carbonates.

Beneath the surface, the action of dissolution has created extensive horizontal maze of cave passages, which host speleothem carbonate deposits.

The Caves

Atiu is a composite island, with a volcanic core, rimmed by carbonate rocks (Mylroie & Mylroie, 2007).

The makatea is a limestone, which formed in seawater and was originally born as a mixture of lithified reefs and microatolls, loose carbonate grains and lithified beachrock (cemented beach rubble and grains). The original reef and lagoon deposits were transformed into a highly porous rock through a process known as dissolution-reprecipitation. This process created pores and fissures of various sizes on the one side and pervasive cementation on the other. Thus, the pattern of porosity of the makatea limestone is unpredictable, which results in different clustering of speleothems within the caves.

Pou Atea Cave. Photo by Garry K. Smith

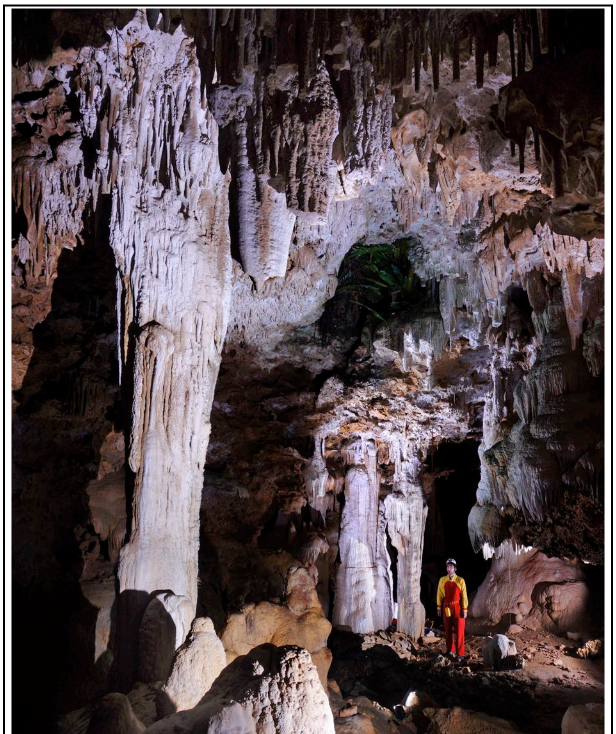
Garry and Mohammadali surveying in Pou Atea Cave. Photo by Garry K. Smith

Silvia with pool speleothems in Nurau Cave. Photo by Garry K. Smith

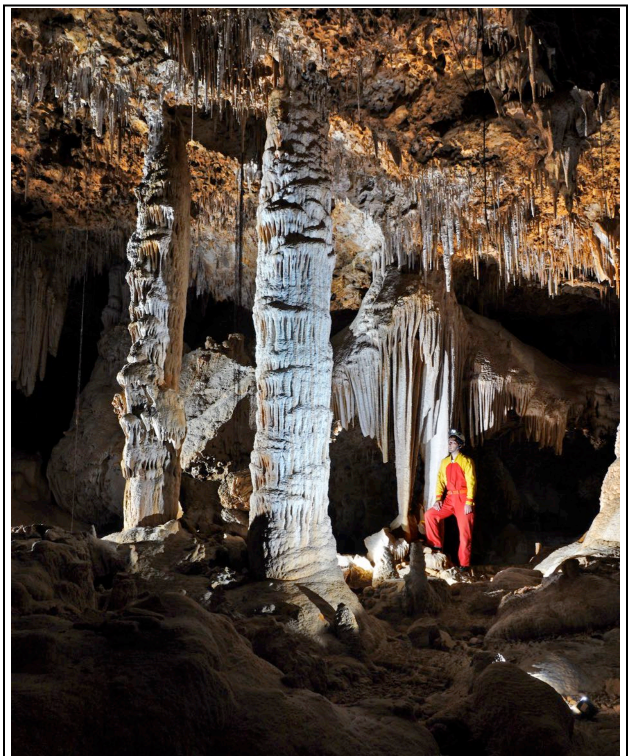
Commonly, Atiu caves are extensive horizontal maze systems with interconnecting large chambers and passages. Navigation through these labyrinths can be confusing without a quality map as a reference. Typically, the larger chamber ceilings extend to within just a couple of metres of the surface, and the lower parts of the caves reach the water table at a depth of approximately 10 to 18 metres. Some caves contain deep pools of crystal clear aqua-coloured water and those closer to the coast generally have water level fluctuations influenced by the ocean tides. Cave entrances are often located at the base of collapse dolines, created by the collapse of thin roofs of large voids formed at the top of the freshwater lens (Mylroie and Vacher, 1982). The ceilings of large chambers may reach all the way to the surface, allowing some light to penetrate into the cave, as well as tree roots. The existence of many stalagmites and flowstones on the cave floor suggests that the current hydrology is mostly vadose. In many places stalagmites have fused with stalactites to become columns, reaching the ceiling in large chambers and are now supporting the thin limestone layer above, preventing it from collapsing. Percolating waters saturated with calcium carbonate have also created cave pearls up to 50mm diameter, which cover vast areas of the cave floor between mazes of rimstone dams.

Andrea, Adam and Mohammadali collecting water samples in Nurau Cave. Photo by Garry K. Smith

Map-eating crab in Nurau Cave. Photo by Garry K. Smith



Skylight #1 chamber in Pou Atea Cave. Photo by Garry K. Smith



Mohammadali in Pou Atea Cave. Photo by Garry K. Smith

Occasionally the clicking sound of echo locating Kopeka (Atiu swiftlet) could be heard as they navigate the cave passages in total darkness. Every cave appears to have a healthy population of crabs up to the size of a spread human hand.

Skylight #5, Pou Atea Cave. Photo by Garry K. Smith

Crab in Nurau Cave. Photo Garry K. Smith

Val Aruruku Cave. Photo Garry K. Smith

Pou Atea Cave (also spelt as Pau Atea)

This cave has five entrances, two of which are free-climbable. The other three require vertical caving gear to enter. There are numerous large maze passages and chambers with massive columns, which majestically appear to be the only support holding the large expanses of roof up. Evidence of speleothem extraction by the early island inhabitants can be found throughout the cave. It has a surveyed length of 965m and the depth from makatea surface to the water table of 18 metres. The cave is not far away from the contact with the eroded volcano, and red soil created by the weathering of volcanic rocks fills pockets and ridges between karren and pinnacles. The stalagmites from this cave appear to consist of porous calcite and compact calcite layers. These two diverse calcites testify the alternation of different hydrologic regimes, with the porous calcite full of particulates likely forming when the infiltration is fast enough to carry soil particles to the stalagmites.

Columns in Pou Atea Cave. Photo by Garry K. Smith

Sea cliffs (6 m high), beach and logoon, Atiu Island.
Photo by Garry K. Smith

Mohammadali near dripstone pools, Pou Atea Cave.
Photo by Garry K. Smith

Nurau Cave

The entrance to this cave is at the bottom of a large collapse doline approximately 18 metres diameter by 5 metres deep. At the back of the cave there is a clear deep aqua coloured lake with a surface area of approximately 3 x 5 metres. The lake was explored by Australian divers, David Goldie and Paul Tobin in 1997, who reported that it leads to an extensive underwater labyrinth of passages. They produced a survey map from their exploration. Then in 2017, Rod Obrien and Bruce Clulow dived the lake and discovered more passage. They surveyed 320 metres of underwater passage to a depth of 12m and reported that the cave continues in passage with water flow, well past their furthest survey point. They saw an abundance of aquatic life such as eels and fish and observed a considerable quantity of large underwater speleothems. (Obrien – pers. comm.)

At the time of our visit the lake had a scattered array of calcite rafts over the surface. This cave also had evidence of speleothem extraction by the early island inhabitants. The total survey length of the dry part of cave is 407m and a depth of 14m from makatea surface to the water table. This cave has honey-coloured stalagmites consisting mostly of compact and very hard calcite. The dark colour is commonly related to the presence of organic compounds.

Vai Araruku Cave

This cave was originally used as a water source by the early inhabitants of the island. The large sloping entrance is located at the base of a cliff on the east side of a collapsed doline. It has a total surveyed length of just 61m and a depth of 17.6m from the surface of the makatea to the water table. The cave has several interconnected pools of deep clear aqua-coloured water. Fish, eels and crabs were spotted in the pools.

Speleothems in Pou Atea Cave. Photo by Garry K. Smith

Expedition Logistics and activities

We flew from Sydney to Rarotonga with Air New Zealand and then on to Atiu with Air Rarotonga. Thankfully our hosts at the Atiu Villas accommodation knew of our arrival time and had arranged for a couple of vehicles to pick us up from the small airport, which for the most part is unmanned. It should be pointed out that the Air Rarotonga twin propeller planes are small and weight restrictions mean that some of your luggage may arrive on another flight if the seats are all allocated. There is a shop on the island with limited supplies, so if visitors have specific dietary requirements or need special equipment then it is worth organising this in advance with your accommodation provider or do a grocery shop in Rarotonga and have it flown to Atiu. There are limited numbers of motorbikes and vehicles, which can be rented for transport around the island.

Our expedition members brought all the supplies we needed on Atiu for the research work, which included surveying, photography, cave monitoring and water collection equipment.

The caves were surveyed with a Leica Disto X310, fitted with a DistoX2 upgraded kit to allow measurement of inclination and bearing in addition to distance. As the survey data was being recorded by the laser DistoX2, it was automatically uploaded to a Samsung Galaxy S2 8.0 tablet and into a cave survey drawing program called TopoDroid. This setup allowed disto measurements to be taken by one person, while another accurately sketched the cave and added details on the tablet, at the same time. The TopoDroid program makes it easy by calculating the true horizontal and vertical true lengths for each measurement (radials and legs) and draws them as accurate lines for the plan and section views.


Tree on the track to Pou Atea Cave. Photo by Garry K. Smith

Surveying of the caves in places was made difficult by crabs eating the pink fluoro flagging tape, which was used to mark stations. It was difficult to verify loop closures when the tape was gone by the time we got back to the station! On one occasion I had a tug-o-war with a crab, determined to drag my flagging tap down it's hole between the rocks. Later on a crab grabbed our paper map and began devouring it. There were several species of crab throughout the caves and they were everywhere. So, no leaving lunches, paper maps or flagging tape unattended.

Cave monitoring consisted of measuring the concentration of carbon dioxide in the cave air, measuring the drip rate (time elapsed between two drops) at various sites, collecting water samples for trace element analyses, measuring water pH and electrical conductivity, measuring dissolved carbonate content in the dripwater, and carrying out experiments of calcite precipitation in the cave. All of this information is then used to interpret the record from the stalagmites, with the ultimate goal of advancing our knowledge on the effects of climate change.


Marae (sacred ceremonial site) made from stalagmites and columns, Atiu Island. Photo by Garry K. Smith

Photography

As part of the research project, photographs had to be taken of all aspects of the cave including passages, chambers, speleothems, research sampling and fauna. For this purpose a Sony RX10IV camera was used in conjunction with Metz 30BCT4 flashes, fitted with Firefly slaves. This allowed photos to be taken with up to 5 flash units going off at the same time. Ideal for capturing the true beauty for large chambers and passages.


Pou Atea Cave, Atiu Island, Cook Islands. Photo by Garry K. Smith

Special thanks to

The local Council of Atiu, Roger Malcolm at Atiu Villas, the landowners/custodian of the land and all the wonderful people in Atiu, the Australian Research Council for supporting the research 'South Pacific and Australian hydroclimatic history recorded by stalagmite calcite fabrics' through a DP grant, Prof. Dave Mattey for setting the first cave monitoring at Atiu.

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