Evidence of paleoseismicity in a flowstone of the Observatoire cave (Monaco)

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Han 98 -Tectonics, karst and seisms

Evidence of paleoseismicity in a flowstone of
the cave of the Observatoire (Monaco).
Indices de paléosismicité dans un plancher
stalagmitique de la grotte de l'Observatoire (Monaco)

Eric GILLI

RESUME:

La grotte de l'Observatoire, située au cœur de la Principauté de Monaco, est une cavité d'origine tectonique très concrétionnée. Elle est placée dans un environnement favorable aux recherches de paléosismicité. Les séismes de magnitude inférieure à 3 sont fréquents dans ce secteur mais des épisodes plus importants sont connus. Dans la grotte, de nombreuses chutes de fistuleuses sont attribuables au séisme ligure de 1887 durant lequel des dégâts d'intensité VII ont été signalées à Monaco. Un forage carotté a été réalisé dans un plancher stalagmitique pour y rechercher des traces de séismes anciens. L'examen d'une coupe révèle plusieurs niveaux de chutes, probablement témoins de séismes inconnus. Une datation du niveau de chute au ^{14}C donne un âge supérieur à la limite de la méthode.

Mots clés: fistuleuse, forage, Monaco, paléosismicité, spéléothème.

ABSTRACT:

Monaco is a medium seismicity zone. The Cave of Observatoire, a well decorated show cave, is a good place for paleoseismicity studies. On the floor of the cave it is possible to observe a great number of collapsed sodastraws. The breakages are attributed to the 1887 ligurian earthquake. A bore hole in a flowstone shows several levels of collapses that may indicate ancient earthquakes.

Key words: borehole, Monaco, paleoseismicity, sodastraw, speleothem

1. — PRESENTATION

1.1. — Description and history

The Cave of the Observatoire (fig. 1) is located in the Rock of the Exotic Garden in Monaco. The entrance was closed but it was excavated for archeological purpose and new parts were then discovered. In 1948, the cave was adapted for tourism.

The entrance of the cave is a narrow descending gallery that is partially artificial. It goes to a depth of 50 m to a group of very well decorated large rooms. Before the rooms, a lateral gallery goes to a deeper zone, where, after a series of narrow passages, it is possible to reach the water table at a depth of 80 m (Gilli and Mangan, 1989).

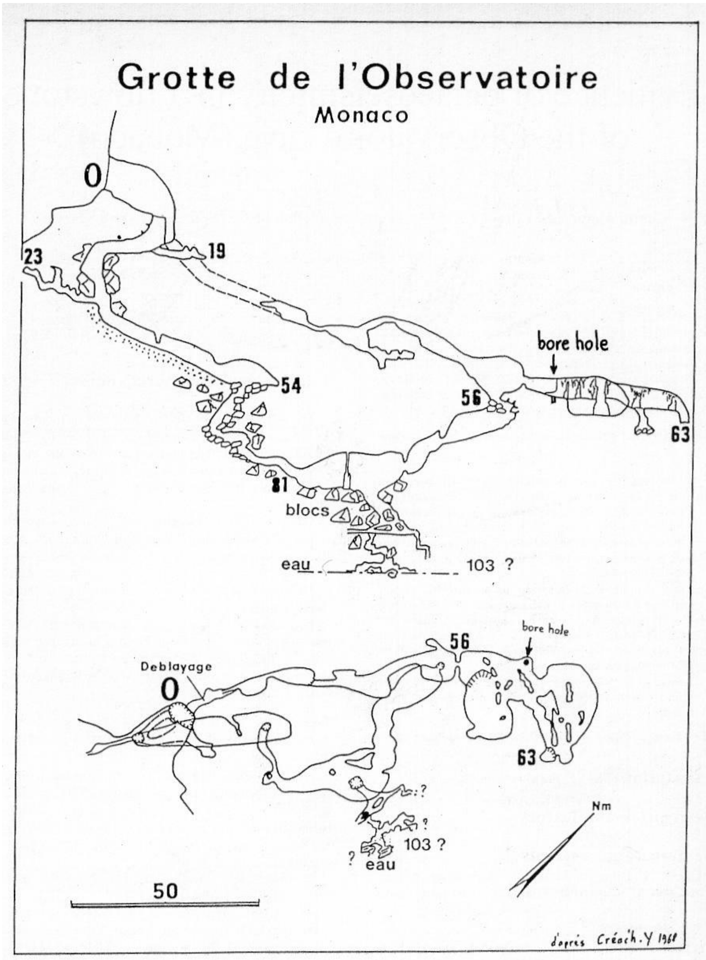


Fig. 1: Map and cross section of the cave of the Observatoire (Monaco).
Plan et coupe de la grotte de l'Observatoire (Monaco).

1.2. — Regional structural context.

Monaco unit, where the cave is located, belongs to the south-western front of the "Arc de Nice" subalpine chains, whose settlement results from the rising up of Argentera-Mercantour (Alps) and the detachment of its sedimentary belt over Triassic clays during alpine orogenesis.

This flexible architecture with parallel overthrusting units is complicated by a plio-quaternary shortening that caused extrusion of the Jurassic blocks inside the cretaceous masses; this increased the tectonic cut of sedimentary series by renewed moving of the different fault families.

The structural features of Monaco area were influenced by large sinistral strike-slip faults that formed lateral pitches during the arriving of alpin overlaps and by the presence of front-country shallows that formed front buffers (Mangan and al, 1994).

1.3. — Geological description of the cave:

The cave is in a narrow limestone block which is limited by a thrust fault, at the southern part and by a vertical fault at the northern part. This tiny block that has moved several times during its geological history is now intensely fractured. The different parts of the cave are aligned on a tectonic canvas (fig. 2)

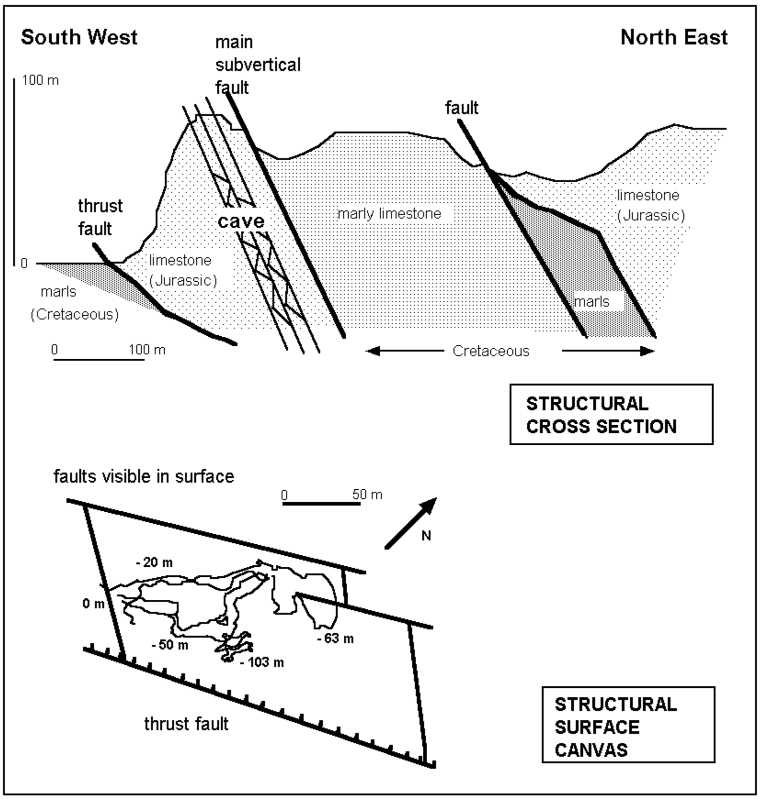


Fig. 2: Structural context of the cave of the Observatoire (Monaco).
Contexte structural de la grotte de l'Observatoire (Monaco).

A more precise study should be done but it is probable that this cave is of tectonic origin. The voids are individualized between two faulted planes that surround a crushed zone (fig. 3). The rocks of the crushed zone migrate toward the bottom of the cave. This may be caused by dissolution in the karstic water table. Renewed movement of the faults may also explain the rocks migration.

2. — SEISMOTECTONIC ANALYSIS

2.1. — **Historical seismicity**

Like the whole of the Côte d'Azur area, the Principalty of Monaco is considered a medium seismicity area that is periodically shaked by small earthquakes.

The last destructive one was the Ligurian earthquake in 1887 (fig. 4). The estimated magnitude was 6 - 6.5 . It caused damage in Monaco with an intensity greater than VII (Lambert et al, 1997). The last important earthquake was a Ms 4.7 one in February 1995. The epicenter was in the sea, south to Monaco.

Monaco was probably affected by the most important Provence earthquakes in 1494, 1564, 1618, 1644, (Lambert et Levret-Albaret, 1996), but it is difficult to evaluate the damages and the local intensity as the population was not important at this time.

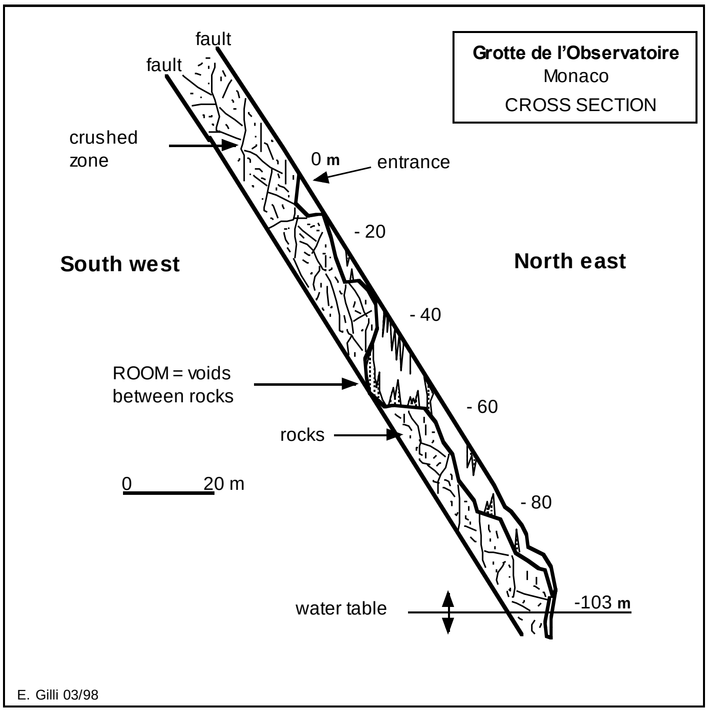


Fig. 3: Schematic cross section of the cave of the Observatoire (Monaco).
Coupe schématique de la grotte de l'Observatoire (Monaco).

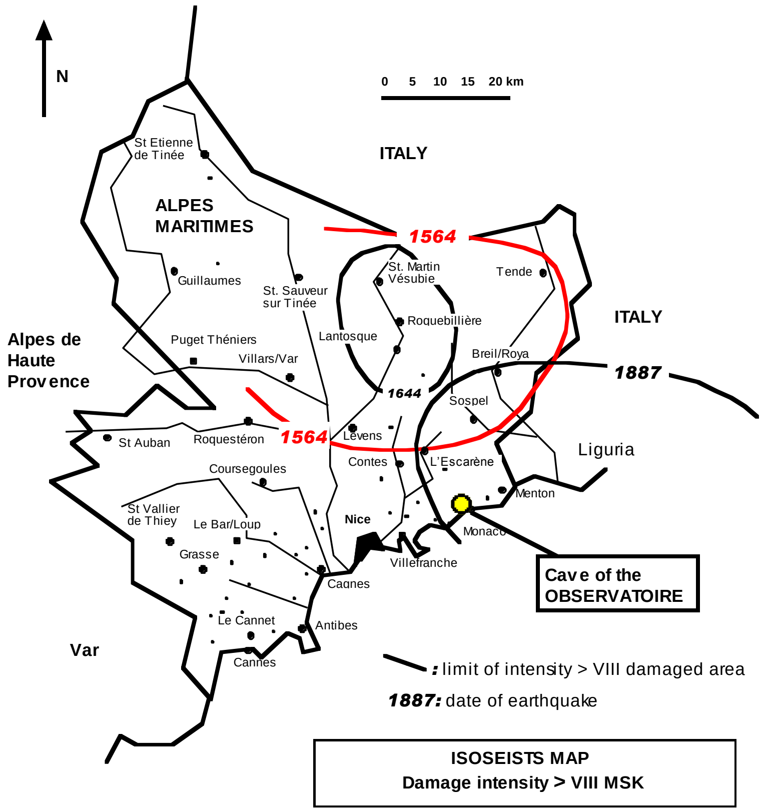


Fig. 4: Isoseist map of the main earthquakes in Alpes Maritimes (France).
Carte d'iso-intensité des dégâts des principaux séismes des Alpes Maritimes.

2.2. **Study of underground damages.**

In the cave there is evidence of damage to stalagmites and calcite pillars. These had first been attributed to subsidence as the cave is filled with crumbled-down rocks. A more precise inspection revealed a great number of collapsed sodastraws and small stalactites in places where subsidence is not possible.

Sodastraws are fixed on the flowstone and sometimes inside a calcite coating (phot. 1). The thickness of the coating and the location of some sodastraws prove that these damages were not caused by human presence. The cave was virgin until the beginning of the works in 1946 and the damages caused by the works are not yet covered with new calcite.

Phot. 1: Fragments of collapsed sodastraws on a flowstone in the cave of the Observatoire (Monaco).
Fragments de fistuleuses sur un plancher stalagmitique de la grotte de l'Observatoire (Monaco).

The collpases of sodastraws may be caused by a seismic shake. This was described in Turkey (Gilli, 1995) and in St Paul-de-Fenouillet (France) (Gilli et al, 1996). Other causes of breakage are however possible:

- action of cave bears, but no signs of these animals were found in the cave,
- action of men, but the cave was closed before the fitting works and most of the places are difficult to reach,
- subsidence when clay is washed out below stalagmites, but here, the formations are not founded on clay,
- waterflows in phreatic active caves, but there is no water flow in the cave
- movements of cave filling-in, but there is no sign of important filling-in.

As these different points are eliminated, it is possible that the damages observed in Monaco cave were caused by the ligurian earthquake in 1887. This hypothetical age is only based on the light calcite coating that could indicate a recent age. A more precise dating has to be done (uranium series and ^{14}C).

2.3. — Research of ancient damage.

Since this cave has a tectonic origin and is located on a limestone crest, it is a good place to look for ancient signs that are fossilised in flowstones (fig. 5). Furthermore, the cave was virgin and the speleothems were already damaged when the cavers arrived in the rooms. We have done several bore holes below well decorated ceilings. We have looked for basin-shaped places that could have collected collapsed sodastraws. The difficulty was to estimate the underground shape of the basins. For instance, if the substructure of a present basin was a declivous flowstone, the collapsed sodastraws have rolled out of the bore hole place.

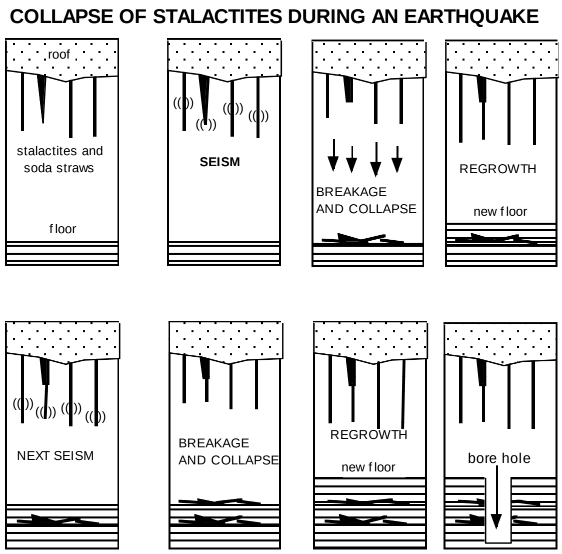
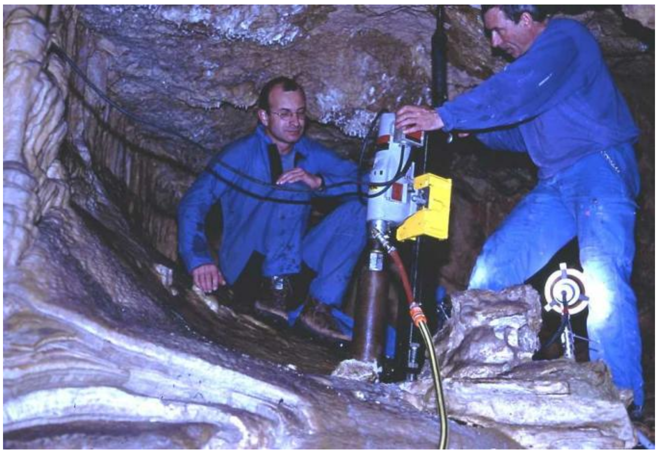


Fig. 5: Principle of ancient seisms recording in a cave flowstone.
Principe de l'enregistrement des séismes anciens dans un plancher stalagmitique.

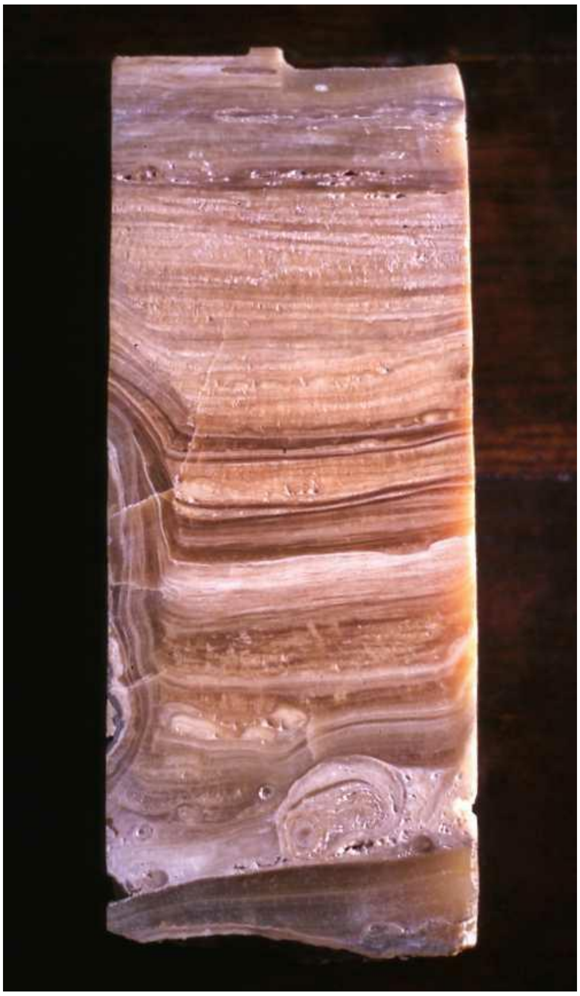


Phot. 2: The drilling machine used for the bore hole in the flowstone in the cave of the Observatoire (Monaco)
La machine de forage utilisée pour le sondage dans le plancher stalagmitique de la grotte de l'Observatoire (Monaco)

Phot. 3: Flowstone sample collected in the cave of the Observatoire (Monaco).
Echantillon prélevé dans le plancher de la grotte de l'Observatoire (Monaco);

A drilling machine was loaned by oceanographic Museum of Monaco (phot. 2). The equipment was able to collect samples 15 cm large and 50 cm long. Three drills were realised but only one was totally successful (phot. 3). The sample was cut and polished.

On the section, several levels of collpased sodastraws are visible (fig. 6, phot. 4).
At the top, a sodastraw, that was visible on the flowstone, is partially covered with a 6 mm thick calcite coating. If the cause of the breakage is the 1887 earthquake this amount was produced in 100 years.
3 cm below the top, a second level shows only one soda straw.
At 9 cm, there is the top of a cave formation which is probably a small stalagmite as there is no central pipe but a little stone heart.
At 17 cm, 3 objects could be pisolites (cavern pearls)
At 18 cm, a stalactite is visible and an object that could be a simple stone, is visible on the side of the sample.
We observe then several sodastraws from 18.5 cm to 21 cm. They appear to be organised in three levels, but it is possible that there is only one level.
A 1 to 3 cm thick beige calcite bed separates this zone from the substratum (black limestone).



Phot. 4: Polished section of the sample where different collapse levels are visible (cave of the Observatoire, Monaco).
Coupe polie de la carotte montrant différents niveaux de chutes dans la grotte de l'Observatoire (Monaco).

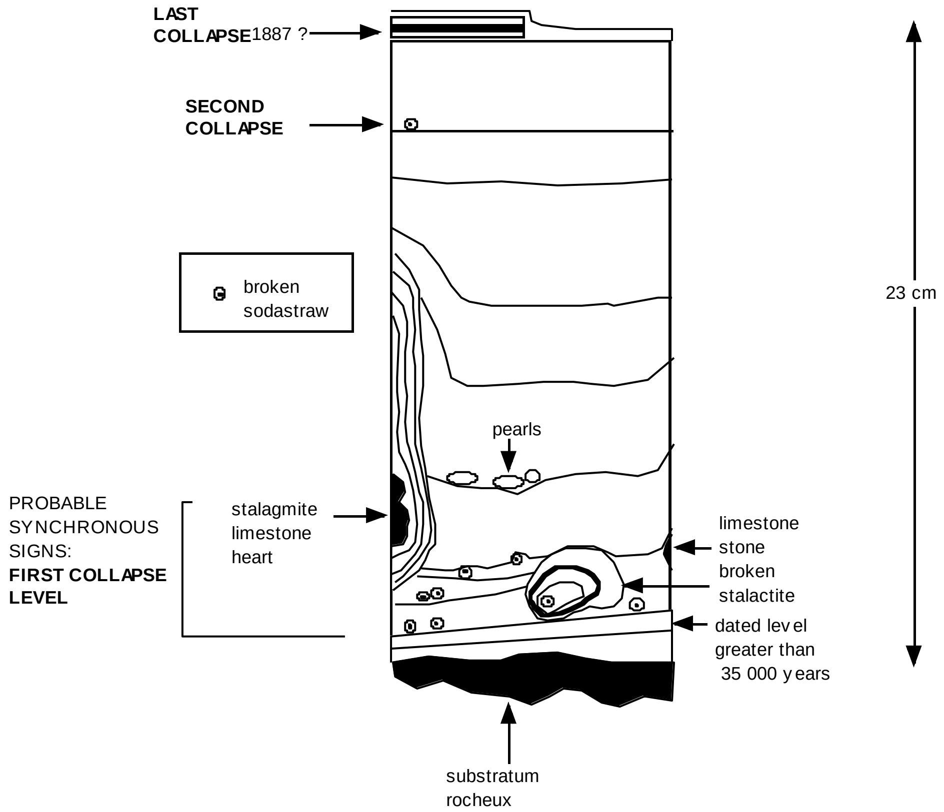


Fig. 6: Schematic section of the sample in the cave of the Observatoire (Monaco).
Coupe schématique de la carotte de la grotte de l'Observatoire (Monaco).

2.4. — Interpretation:

The polished cross section shows 3 or 5 levels of collapses :

- a first level, at the top of the sample, is attributed to the 1887 earthquake.
- a second level with only one collapse could be the 1564 earthquake.
- a third level with important collapses of sodastraws, stalagmites and stalactites is an older and probably more destructive shake.

The substratum of the last level has been dated with radiocarbon method, but the age is out of the method limit (higher than 35 000 yrs).

3. — CONCLUSION:

On the flowstone of the Observatoire Cave recent collapses are visible that are attributed to 1887 earthquake. The bore hole indicates that similar collapses occurred 2 or 4 times in the past.

The regularity in the calcite deposit and the absence of hiatus, eliminate a cause inside the cave. So we suppose that the breakages were caused by ancient earthquakes. We have to remain prudent and to complete these investigations with dating on the different levels where collapses are observed. The same operations must be done in different parts of the same cave but also in different caves in Ligurian area.

Similar observations have already been done in two caves near Finale Ligure (Italy). New research will be done on the fragments' orientation to see if a preferential direction is observable, this could give information on the shake direction if the seismic cause for the damage is accepted (Gilli and Delange, 1996).

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