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EVIDENCE OF PALAEOSEISMICITY IN THE KARSTIC CAVITIES OF THE GRANDS CAUSSES AS SHOWN IN THE AVEN DE LA PORTALERIE (LARZAC, AVEYRON, FRANCE)

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(13 figures incl. 4 photos, 1 table)

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SUMMARY
Instrumental and historical seismicity data reveal that the Grands Causses are a seismically and tectonically stable area. Conventional neotectonic analysis methods give similar results. However, the Aven de la Portalerie on the Causse du Larzac does show some evidence of a degree of seismotectonic activity expressed by the presence of speleothem breaking. A large number of stalagmites have been broken off and the break often repaired by a subsequent growth of calcite. Stalagmitic floors have been fractured and displaced by fault movements occurring after their formation. This destruction would seem to have been caused by several earthquakes, since stalagmite fragments lying on the ground show that they had already been broken and built up again by several centimetres.
In this context of apparent stability, only the endokarst is capable of retaining and revealing evidence of relatively recent earthquakes whose chronological order can be established using various dating techniques.

KEYWORDS: palaeoseismicity, speleothem, U/Th dating, aven de la Portalerie, Larzac, Aveyron, France.

RESUME. Indices de la paléosismicité des Grands Causses dans les cavités karstiques: l'exemple de l'aven de la portalerie (Larzac, Aveyron). Les données de la sismicité instrumentale et historique font apparaître les Grands Causses comme un secteur sismiquement et tectoniquement stable. Les méthodes conventionnelles de l'analyse néotectonique vont dans le même sens. Pourtant, sur le causse du Larzac, l'aven de la Portalerie présente plusieurs indices d'une certaine activité sismotectonique matérialisée par le bris de spéléothèmes. De très nombreuses stalagmites sont tronquées et une nouvelle repousse de calcite scelle le plus souvent les cassures. Des planchers stalagmitiques sont fracturés et décalés postérieurement à leur formation par des mouvements de failles. Ces destructions semblent être le résultat de plusieurs séismes puisqu'un fragment de stalagmite, couché au sol, présente déjà une ancienne cassure scellée par une repousse de plusieurs centimètres.
Dans ce contexte de stabilité apparente, seul l'endokarst semble donc capable de conserver et de révéler des traces d'une certaine activité sismotectonique. Il permet aussi, à l'aide des diverses possibilités de datations, de situer chronologiquement ces événements.

MOTS-CLES: paléosismicité, spéléothème, datations U/Th, aven de la Portalerie, Larzac, Aveyron, France.

1. Introduction

The cavity is located in the northern part of the Causse du Larzac (Aveyron), to the north of a hamlet called La Blaquererie (Fig. 1). Its opening is at the lowest point of a huge doline lying above the polje of Hospitalet (Ambert, 1994; Bruxelles, 2001). The Aven de la Portalerie is one of the very few cavities on the Causse de l'Hospitalet to have more or less horizontal galleries lying close to the surface. In fact, as with the other, primarily vertical, cavities in this part of the causse, this aven gives rise to a number of observations with regard to detritical and chemical filling.

2. Tectonic and seismotectonic data concerning "the Causse de l'Hospitalet"

2.1. Tectonic framework

The "Causse de l'Hospitalet" is flanked to north and to the south by two great overall east-west faults stemming

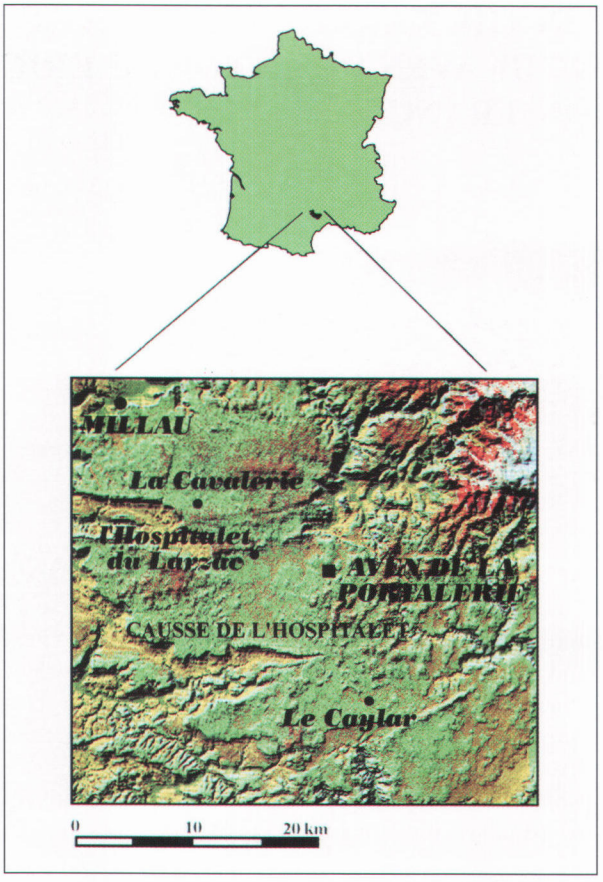

Figure 1. Location map of the aven de la Portalerie.
Figure 1. Carte de situation de l'aven de la Portalerie.

from Pyrenean tectonic activity (Fig. 2). These are the reverse faults of La Pezade to the south and Hospitalet (Arre-Alzon) to the north. The latter has an offset of almost 400 metres at the level of the causse itself.
A series of submeridian, normal vertical faults (NE-SW to NW-SE), lowers the eastern end of the causse (Fig. 3). They provide a point of contact between the bathonocallovian dolomite and the upper Jurassic limestone (Oxfordian-Kimmeridgian). The main fault, that is responsible for this abnormal contact, is at 200 metres to the east of the cavity entrance. Its offset reaches 100 metres to the east of La Blaquererie but no more than about twenty around La Portalerie. This type of structure is often associated with volcanic events.

2.2. Volcanic events

The volcano of la Blaquererie (at about 1 km to the south of La Portalerie) is the only one known in this part of the causse (Fig. 4). It consists of a system of highly-altered flows (Puech Grand) and an intrusion assumed to be the basalt emission point (Puech Prieur). The basalt has been dated between 1.63 +/- 0,005 million years and 1.50 +/-0,007 million years (Gillot, 1974).

2.3. Seismotectonic data

From a tectonic and seismic point of view, the Grands Causses are considered to be a stable region. Traditional methods based on historical and instrumental seismicity show that the Larzac has been exempt from this type of event in recent periods (Grellet et al., 1993). As far as earlier periods are concerned, the neotectonic map (Debrand-Passard et al., 1984) shows no information on the sector either, apart from volcanic activity in the Plio-Quaternary and early Pleistocene times.

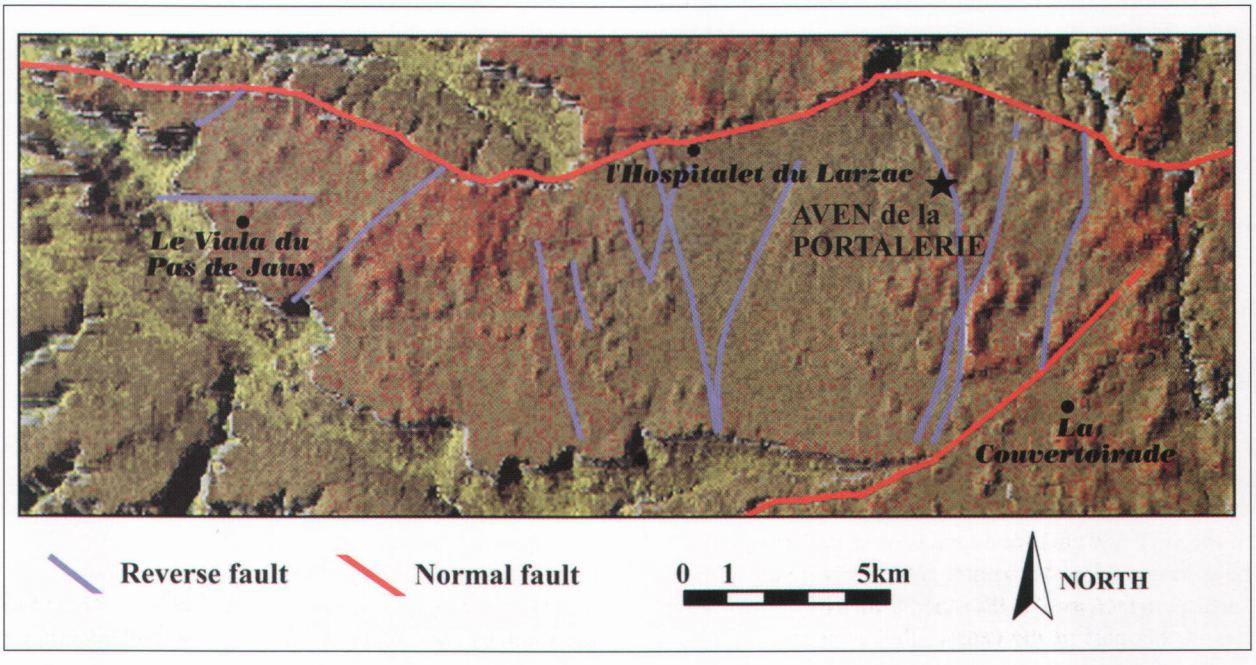

Figure 2. Tectonic diagram of Causse de l'Hospitalet.
Figure 2. Schéma tectonique simplifié du causse de l'Hospitalet.

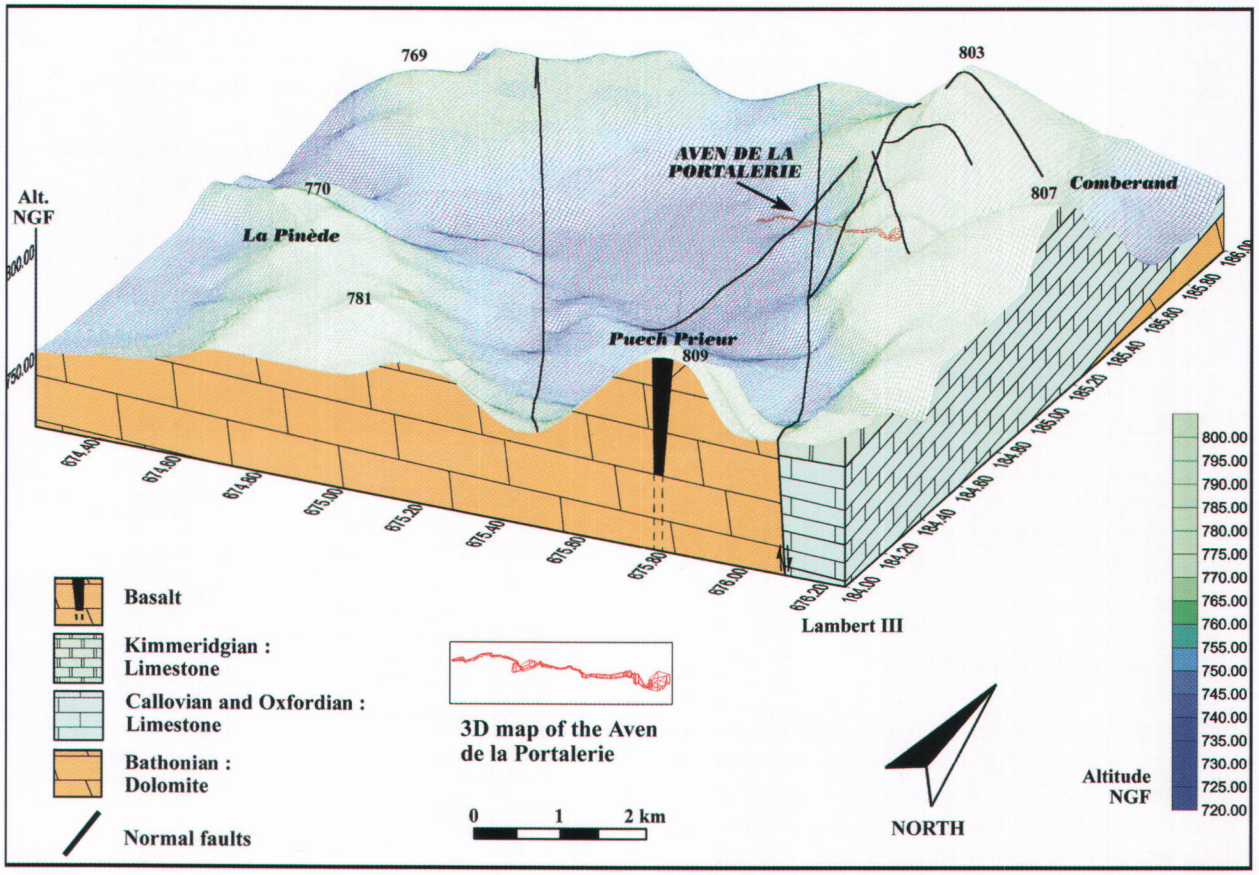

Figure 3. Block-diagram of the Aven de la Portalerie area.
Figure 3. Bloc-diagramme du secteur de l'aven de la Portalerie.

Tectonic and seismotectonic data thus indicate a degree of stability in the causse, at least in recent periods. These factors are confirmed by the surface morphology where substantial faults have been levelled down and have no visible previous offset (Bruxelles, 2001). These data do however contrast with observations made in the Aven de la Portalerie.

3. Evidence of palaeoseismicity in the Aven de la Portalerie

The aven consists of a series of temporarily active galleries culminating in the terminal siphon at –149 metres (altitude: 579 metres). The main gallery is more or less horizontal and is pitted by a succession of wells at the crossing of several faults (Fig. 5). It ends up in a huge hall formed by collapse with highly fractured walls and roof. A tributary gallery measuring 150 metres joins it at the base of the entrance shaft.

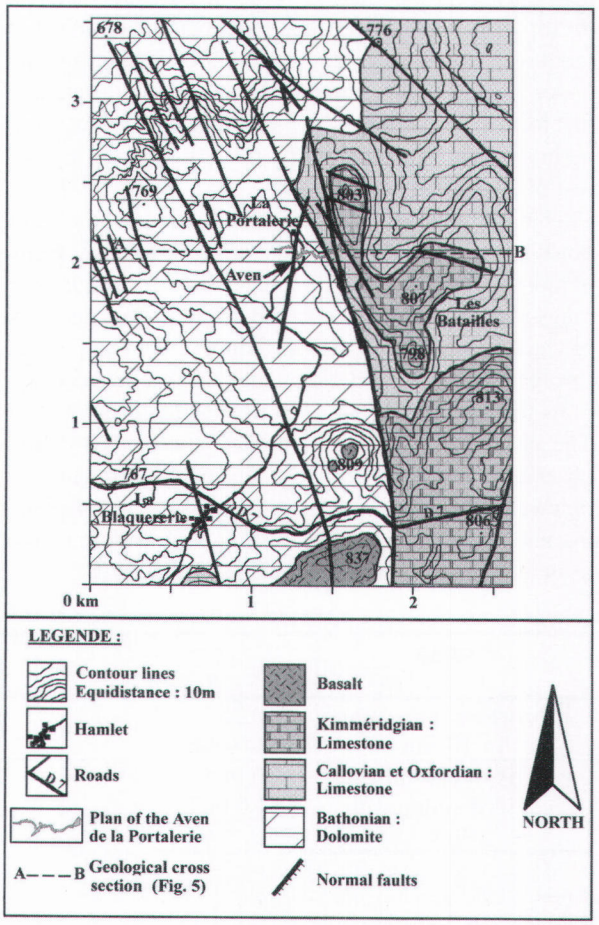

Figure 4. Geological map of Portalerie area.
Figure 4. Carte géologique du secteur de la Portalerie.

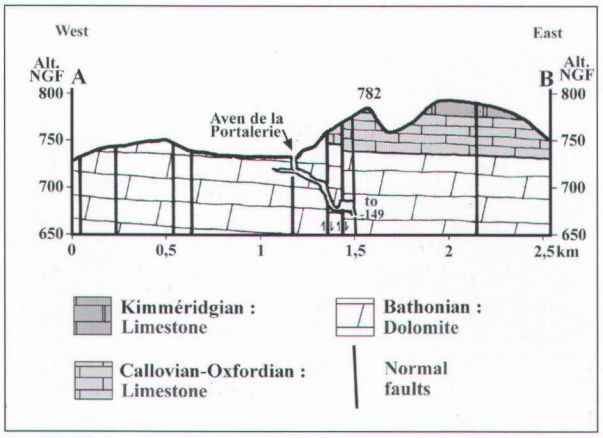

Figure 5. Geological cross section along main gallery of the aven de la Portalerie (Larzac, Aveyron).
Figure 5. Coupe géologique dans l'axe de la galerie principale de l'aven de la Portalerie (Larzac, Aveyron).

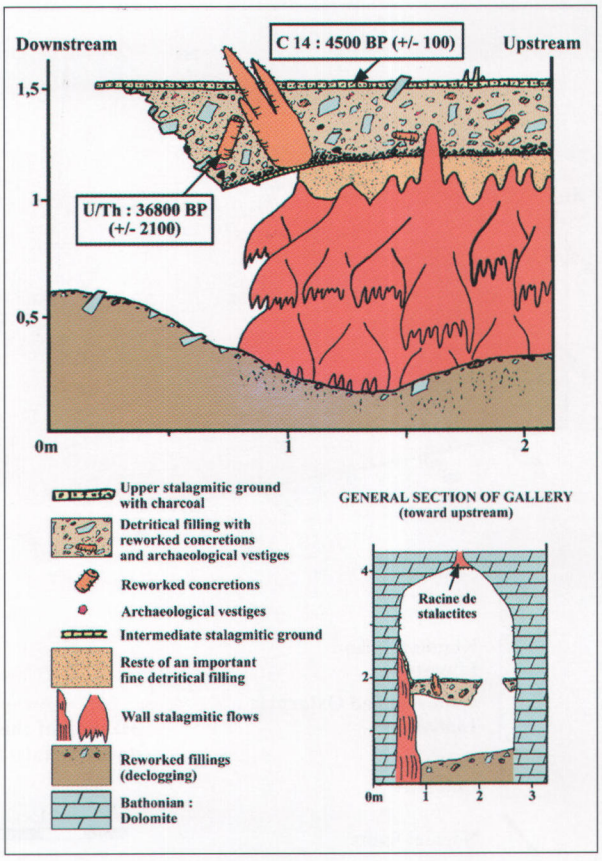

Figure 6. Cross section of tributary gallery filling in the aven de la Portalerie.
Figure 6. Coupe du remplissage de la galerie affluente dans l'aven de la Portalerie.

3.1. Fillings of the tributary gallery

The gallery is partially clogged by considerable detritical and chemical filling (Fig. 6). Declogging makes possible to observe a sedimentary sequence representative of the cavity recent evolution (Bruxelles, 1995). This starts with a group of stalagmitic flows strongly corroded under detritical filling that is fine at the base and coarse at the top. This upper level contains many fragments of shattered and reworked calcite concretions. The top of the upper part of this formation is enriched with charcoal that forms a centimetric layer. Many fragments are caught up in a stalagmitic ground of 2 to 4 cm that overlays the rest of the sediments.
U/Th dating (Table. 1) of one of these reworked concretions indicates 36,800 years BP (+/- 2,100). Its reworking is more recent since the detritical filling to which it belongs also contains several fragments of pottery and bone of chalcoholithic age. The ^{14}C dating of the charcoal below the upper stalagmitic ground confirms the recent age of its formation: 3,367 – 2,888 BC (calibrated age).
The presence of numerous broken concretions can be observed throughout the aven. This could be related to a renewal of activity in the cavity (flooding, new hollowing and declogging of the filling) though certain factors to be described later would seem to contradict this hypothesis. It is more likely to be the result of the impact of one or more earthquakes. This is backed up by many other signs observed in the gallery.

3.2. Anomalies in speleothem development

A great number of broken speleothem are spread out throughout the cavity (Fig. 7). The damage has affected many of the stalactites and stalagmites, as well as the calcitic coating that has fossilized small faults. All these fractures and anomalies are similar to those observed in caves in tectonically active regions (Gilli, 1986; Jeannin, 1990 ; Postpischl et al., 1991 ; Bini et al., 1992) or in

Sample	(U) ppm	234U/238U	230Th/234 U	230Th/232 Th	(234U/238U) t=0	Age (in k.a.)
Reworked concretion in filling	0.247 +/-0.006	1.064 +/-0.030	0.288 +/-0.014	17.4 +/-3	1.071	36.8 (2.1/- 2.1)
Displaced and repaired stalagmitic flow	0.084 +/-0.002	1.079 +/-0.027	0.870 +/-0.027	10.7 +/-0.8	1.142	209.4 (25.3/-19.9)

Table 1. U/Th results from two speleothems of the aven de la Portalerie (Yves Quinif, CERAK, Belgium).
Tableau 1. Dosages isotopiques U/Th à partir de deux concrétions de l'aven de la Portalerie (Yves Quinif, CERAK, Belgique).

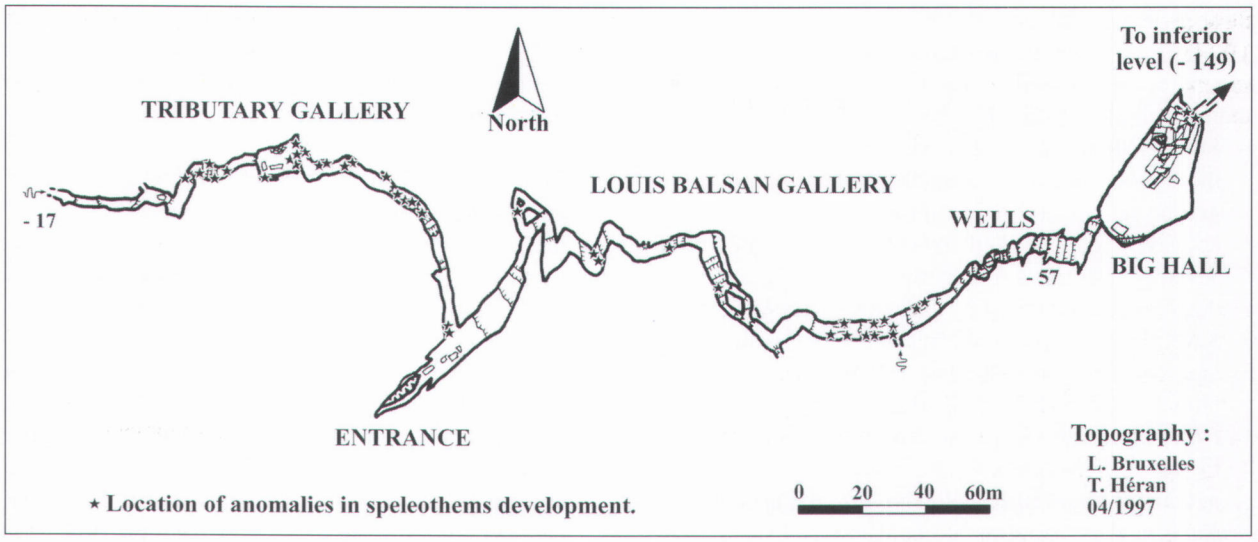

Figure 7. Topographic map of the upper gallery of the aven de la Portalerie showing different points where anomalies in speleothem development have been observed.
Figure 7. Topographie de la galerie supérieure de l'aven de la Portalerie figurant les différents points d'observation d'anomalies de développement des spéléothèmes.

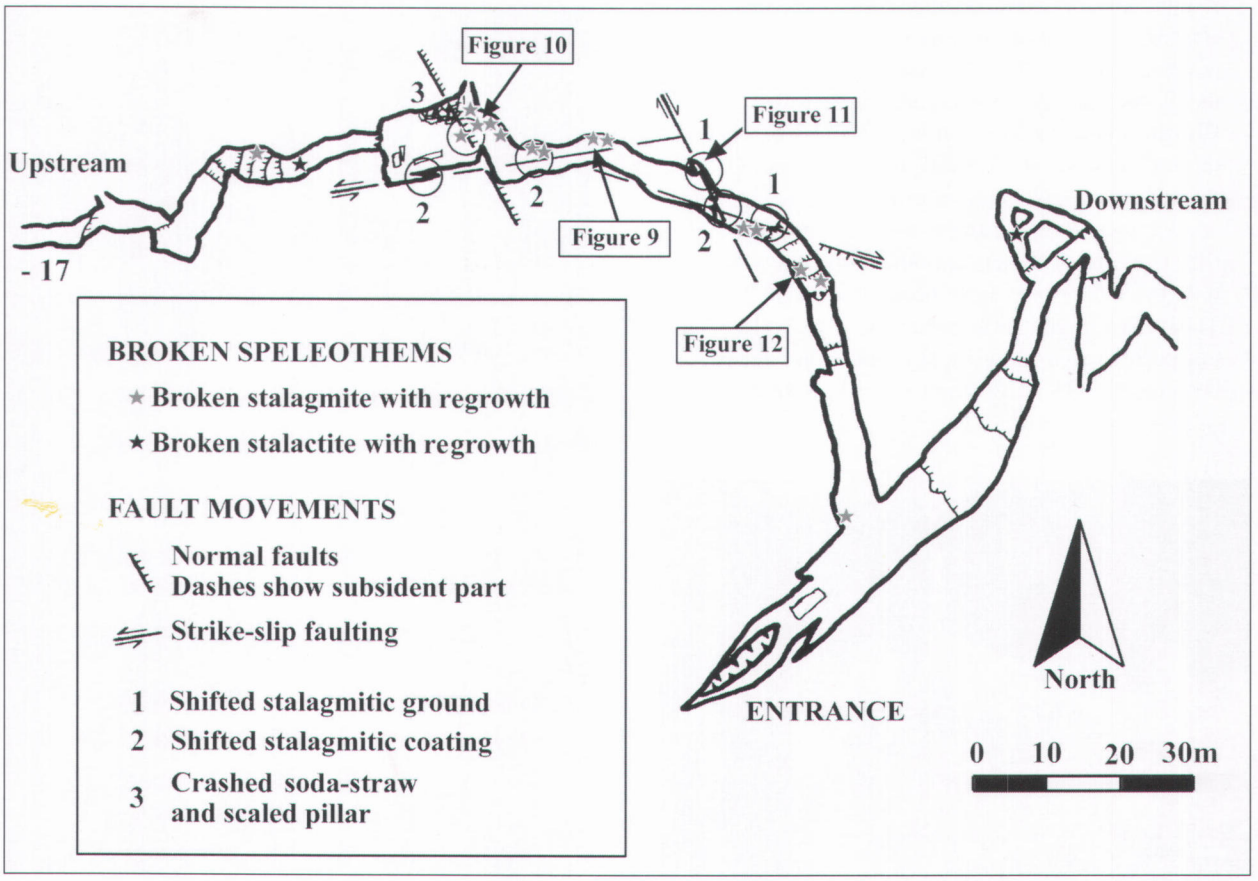

Figure 8. Detailed map showing differerent types of seismo-tectonic events recorded in the tributary gallery of the aven de la Portalerie (Aveyron).
Figure 8. Plan détaillé de la galerie affluente de l'aven de la Portalerie (Aveyron) situant les différents enregistrements d'événements sismo-tectoniques observés.

those assumed to be more stable, such as Belgium (Quinif, 1997), and have been explained as the result of seismotectonic activity. The tributary gallery contains many examples of this (Fig. 8):

– Several dozen of broken stalagmites can be seen throughout the cavity. Some of the fragments on the ground remain at the foot of the stump while the others have been reworked downstream. New growth of several centimetres frequently repairs the breaks and the pieces are bound to the stalagmitic ground (Fig. 9). Several phenomena could be responsible for this damage, such as heavy flooding (Bartholeyns, 1987) or human activity (Rouzaud, 1995):

- Fairly heavy flooding is not impossible in this part of the cave. In this case, the stalagmite fragment would of course be carried away by the current. Furthermore, some of these features are held in steep stalagmitic flows (Fig. 10) and in this position, the slightest hydrodynamic impulse would have automatically cast them to the foot of the structure. Lastly, some of the fragments at the foot of the stump have been carried upstream which, given the way the gallery's morphology functions, is improbable in the case of flooding.
- Prehistoric man visited part of the upper galleries and so could also have been responsible for the breaking. Examination of several features contradicts this hypothesis since several of the broken stalagmites are out of reach or too large. Besides, there is no apparent trace of the blows that would be required to destroy them.

– Broken stalactites with regrowth can also be observed throughout the cavity but they are fewer in number than the stalagmites. Concretion of this aven being mainly conducive to the formation of stalagmites, the stalactites tend to be smaller (in both length and width) and only the longer ones have been affected by breaking. The broken fragments also stay on the ground and have not been carried away by any flooding. Breaks have been repaired by regrowth of several centimetres.

– In the tributary gallery, several stalagmitic grounds have been broken. In all cases, speleothem has occurred on the base rock which means that the action of phenomena such as declogging or sediment settling can be excluded.

- The first, at 100 metres from the start of the tributary gallery, has joined the sides of a small fault (N90°) that steered the channelling of the gallery over a few metres. Breaks recorded in the speleothems reveal a small senestral stripe-slip faulting of about a centimetre.
- A second stalagmitic floor fills a widened fragment oriented 160° N at 50 metres downstream from the first. Its dextral stripe-slip faulting is about 1 cm and looks WSW. The break has been repaired by a calcitic coating and has not been affected by any movement (Fig. 11). U/Th isotopic ratio of the shifted concretion's implies an age of 209,400 years (+25,300/-19,900). Therefore the movement occurred between this date and the formation of the latest calcitic coating which is still to be dated.
- The last example is located at about ten metres downstream from the second. A fracture oriented 110° N

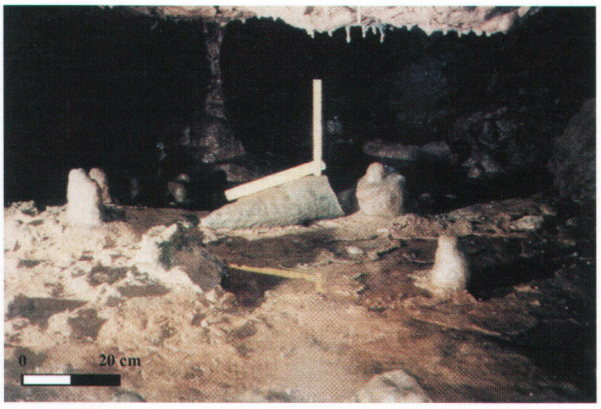

Figure 9. Broken stalagmite with a regrowth. Fragments are cemented to the stalagmitic floor.
Figure 9. Stalagmite brisée avec repousse. Les fragments au sol sont soudés au plancher stalagmitique.

Figure 10. Stalagmitic fragments cemented on a steep stalagmitic flow.
Figure 10. Fragments de stalagmites soudés à une coulée stalagmitiques en forte pente.

Figure 11. Stalagmitic floor broken by fault activity. The broken speleothem is now covered by a new calcitic coating.
Figure 11. Plancher stalagmitique affecté par un rejeu de la fracture qu'il scellait. Un nouvel enduit stalagmitique recouvre le tout.

has given rise to a south-looking rejection of 2 to 3 cm. The fault is quite clear and continues into the base dolomite. No later concretion has fossilised the shift.
- In places, the dolomite roof is covered by numerous little stalactites forming a thin calcite coating. At 45 metres from the start of the gallery, these concretions are affected by a dextral shift of about 1 cm. No further concretion occurred after this break.
- The roof of the tributary gallery is criss-crossed by numerous fractures. In one of them (160° N), a few "soda-straws" have developed between the two sides. The breaks quite clearly reveal the signs of a lengthwise contraction of about 1 cm. They look ENE. On the ground, a stalagmitic pillar positioned on the fault is scaled and confirms the movement observed.

3.3. Significance of the anomalies

The widely observed anomalies in speleothem development reveal that this cave has undergone one or more seismotectonic events. While stalactite and stalagmite rupture can be the result of causes other than seismotectonic, the stripe-slip faulting of stalagmite grounds and calcite coatings proves that new fault movements occurred after the formation of the speleothems.
On the basis of Figures 7 and 8, two remarks may be noted :
- the movements responsible for the rupture of stalagmitic grounds are mainly localised in the tributary gallery. They correspond on the whole to small fault movements;
- broken stalactites and stalagmites with their regrowth are spread over the entire range of the cavity. This manifests the impact of a seismical shock.

The shifts do not seem to be related to the great faults to the east of the cavity that can clearly be seen in the main gallery and in the great hall, but rather to more discreet breaks that affect the tributary gallery. The direction taken by these movements corresponds to older faults or cracks occurring prior to karstification and that steered the hollowing out of part of the galleries. Therefore, the visible shifts are just a new movement of these fractures whose overall direction cannot be ascertained, though they could show that the sector has been disturbed by an earthquake without necessarily indicating a specific tectonic movement. Nearby volcanic activity could well be the cause of these events.
Furthermore, certain features show that several earthquakes did occur. A stalagmite fragment bound to a stalagmitic floor at about fifty metres from the entrance to the tributary gallery had already been broken and repaired by regrowth (Fig. 12). Therefore it was once part of a stalagmite that was previously broken and whose break was fossilised by substantial regrowth (10 cm). A further event destroyed the stalagmite that now lies bound to the stalagmitic ground (Fig. 13). This evidence shows that the Aven de la Portalerie has been affected by at least two earthquakes.

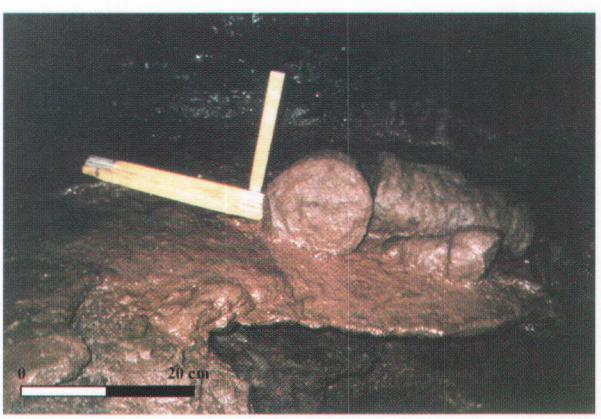

Figure 12. Broken stalagmite. One of the fragments had already an old break and a regrowth of many centimetres. All pieces, together with charcoal are cemented to the stalagmitic floor.
Figure 12. Stalagmite brisée dont un des fragments possédait déjà une repousse de plusieurs centimètres. Les éléments sont tous soudés au plancher stalagmitique à charbons.

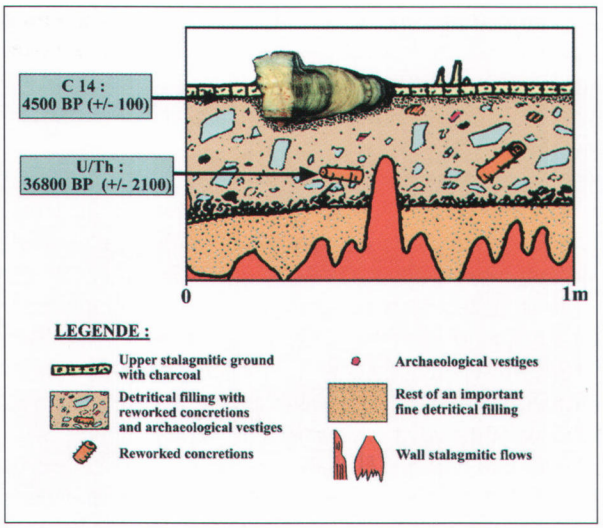

Figure 13. Location of broken stalagmite in tributary gallery filling.
Figure 13. Localisation stratigraphique de la stalagmite cassée avec repousse dans la coupe de la galerie affluente.

Up to now, dating has provided little precise knowledge about the age of these earthquakes. The displaced and recemented floor is dated at –209,000 years (Fig. 10). Dating of the calcite coating which seals the break should give an age bracket for the earthquake. In the upper part of the filling, one of the reworked speleothems is dated at –36,800 years (+/- 2,100). If an earthquake was really the cause of this destruction, then it must have occurred after this date. The filling it belongs to has also reworked numerous chalcoholithic archaeological vestiges and the stalagmitic floor that covers all is more recent than the charcoal dated at 4,500 years BP. The breakage and subsequent reworking of this concretion therefore occurred somewhere between 36,800 and 4,500 BP. Dating of other broken concretions in the filling might help to reduce this time range.
The stalagmite fragment whose initial break has been repaired is bound to the upper ground. It lies at the level of the charcoal dating from 4,500 BP at the top of the coarse clastic formation. Its second fragmentation is therefore later than 4500 BP but earlier than the formation of the stalagmitic ground that partially covers it.

4. Conclusions

The morphology, clastic filling and concretions of the Aven de la Portalerie reveal evidence of several anomalies that could be the result of relatively recent seismotectonic events. Initial dating places them somewhere between the end of the mid-Pleistocene and the end of the upper Pleistocene or in the Holocene.
This intermittence means that the origin of these earthquakes cannot yet be identified, neither can the general direction of the movements that cause concretion shifting. Only the study of several cavities in the sector and systematic gathering of relevant information can provide an overall direction and ascertain the extent of earthquakes in the region.
The faults to the east of La Portalerie are the most active ones on the causse, the more so owing to volcanic activity further south, dating from the early Quaternary. Remains the question of anomalies in the development of speleothems in other zones of the Causse.
In a region like Larzac which on the basis of modern and historical seismic data or conventional neotectectonic analysis, was assumed to be fairly stable, the endokarst is a rich source of information in the study of palaeoseismicity and the search for neotectonic traces that cannot be detected, or have been lost, on the surface. The preservation of information in a protected environment, in addition to dating methods, make karstic cavities an ideal terrain for this type of research.

5. References

AMBERT, P., 1994. L'évolution du Languedoc Central depuis le Néogène (Grands Causses méridionaux, piémont languedocien).
Document n°231 du BRGM, Orléans, 210 p + 3 enclosures.

BARTHOLEYNS, J.P., 1987. Réseau Siebenhengste-Hogant. La crue du siècle et -1000 m à la clé. *Spelunca*, 27: 9.

BINI, A., QUINIF, Y., SULES, O., et UGGERI, A., 1992. Les mouvements tectoniques récents dans les grottes du Monte Campo dei Fiori (Lombardie, Italie). *Karstologia*, 19 : 23-30.

BRUXELLES, L., 1995. Etude des altérites, formations superficielles et endokarstiques du causse de l'Hospitalet (secteur oriental) : conséquences et contraintes pour l'aménagement. Mémoire de DEA, Aix-en-Provence, 62 p.

BRUXELLES, L., 2001. Dépôts et altérites des plateaux du Larzac central : causses de l'Hospitalet et de Campestre (Aveyron, Gard, Hérault). Evolution morphogénétique, conséquences géologiques et implication pour l'aménagement. Thèse, Université de Provence, 266 p.

DEBRAND-PASSARD, S., COUBOULEIX, S., & LIENHART, J.M., 1984. Synthèse géologique du sud-est de la France. *Mémoires du BRGM*, 125, 615 p.

GILLI, E., 1986. Néotectonique dans les massifs karstiques, un exemple dans les Préalpes de Nice : la grotte des Deux Gourdes. *Karstologia*, 8 : 50-52.

GRELLET, B., COMBES, P., GRANIER, T., & PHILIP, H., 1993. Sismotectonique de la France métropolitaine dans son cadre géologique et géophysique. *Mémoires N.S. SGF*, 164, vol. 1, 76 p. + vol.2, 24 fig. + 1 map.

GILLOT, P.Y., 1974. Chronométrie par la méthode K/Ar des laves des causses et du Bas Languedoc : Interprétation. Thèse Sciences, Orsay, 61 p.

JEANNIN, P. Y., 1990. Néotectonique dans le karst du nord du lac de Thoune (Suisse). *Karstologia*, 15: 41-54.

POSTPISCHL, D., AGOSTINI, S., FORTI, P., & QUINIF, Y., 1991. Paleosismicity from karst sediments : the "Grotta del cervo" cave case study (Central Italy). *Tectonophysics*, 193 : 33-44.

QUINIF, Y., 1997. Enregistrement et datation des effets sismo-tectoniques par l'étude des spéléothèmes. *Annales de la Société Géologique de Belgique*, 119 : 1-13.

ROUZAUD, F., SOULIER, M. & LIGNEREUX, Y., 1995. La grotte de Bruniquel. *Spelunca*, 60: 27-34.

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