INCIDENCES OF THE TECTONICS IN THE KARSTIFICATION OF CHALK LIMESTONES IN THE WESTERN PARIS BASIN: EXAMPLE FROM THE PETITES DALES CAVE (SAINT MARTIN AUX BUNEAUX, FRANCE)

Joël Rodet[1], Kun Ma[2], Jean-Pierre Viard[3]
[1]*UMR 6143 CNRS-M2C-Université de Rouen, Laboratoire de Géologie, CNEK, 76821 Mont Saint Aignan, France, joel.rodet@univ-rouen.fr*
[2]*Université de Rouen, UMR 2795 CNRS-IDEES, Institut de Géographie, 76821 Mont Saint Aignan, France*
[3]*Centre Normand d'Etude du Karst et des Cavités du Sous-sol, 97 rue du 8 mai, 27400 Montaure, France*

The classical approach to study the karstification attributes a major role to the structure in the establishment of concentrated drainage of groundwater. This structure, essentially tectonics and stratigraphy, serves to guide the water, which gradually opens up these discontinuities to build a network, from the introduction to the resurgence. This too idealistic view does not reflect the complexity of the establishment of a karst system. Indeed, experience shows that some bedrocks contain karst drains in the absence of any cracking. What's more, some conduits can go through the structural elements without undergoing any morphological changes. In the chalk of Western Paris Basin, the Petites Dales Cave proves an excellent observatory. We have conducted a study on the relationship between the main conduit, restitution collector of the underground system, and observable fissures in the roof and walls of the conduit. Along a drain of 421 m, we counted 374 fissures, the total length of which being a little more than 867 m. Examination of the orientation of the drain and fissures reveals four types of relationship: (1) parallel (2) oblique, (3) perpendicular and (4) no joints. No correlation could be established between the development of the collector and the presence of fissures, other than very occasionally or during episodes of overflow. In fact, the relationship between fissure and karstic conduit cannot be established, therefore it is necessary to introduce other factors in the speleogenesis, such as porosity of the chalky bedrocks, and the direct effect of the hydraulic gradient.

1. Introduction

Typically, it is assumed that the development of karst drains depends on the structure, especially the tectonics. "Structural cracking is the main factor of permeability to water in a limestone" (Jakucs 1977). Explorations in the chalky limestone of the Paris Basin showed that this was not always the case (Rodet 1992). So we started the study on the relationship between drain and fissures in one of the largest caves of Normandy, the Petites Dales Cave.

Petites Dales Cave opens in the eponymous valley, 1.2 km from its outlet on the coast of the English Channel (Fig. 1). Small cavity of only 62 m of development at its speleological recognition in 1966, this site became one of the most important underground excavation sites in France since 1991 (Rodet et al. 2007). To date, with more than 710 m of explored galleries, the cavity is the largest in Seine Maritime. It hosts a multidisciplinary karst research program (Laignel et al. 2004; Rodet et al. 2006), being referenced as the chalk karst of Normandy Region (Rodet and Viard 2009).

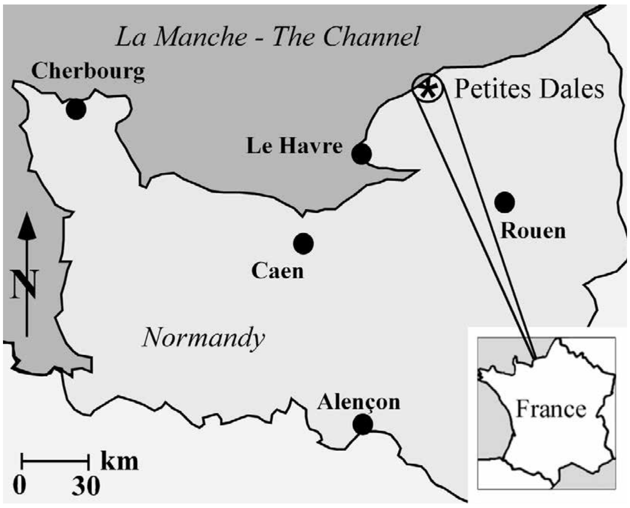

Figure 1. Location of the study area.

As part of this research program, we studied specifically the relationship between visible tectonics and directions of drain to verify the applicability of the concept of the drainage network establishment based on the tectonic frame (Hauchard et al. 2002, 2008) for cavities in chalk. Our approach is limited to observable fissures in the main gallery of the cave between the entrance (topographic point # 1 – pt. 1) and the impact of the first solution pipe (topographic point # 43).

2. Methodology

The topographic map of the Petites Dales Cave was surveyed from a network of fixed and materialized stations, which are therefore easy to locate (Fig. 2).

The topography of the collector was completely established along a length of 460 m, till the foot of the second solution pipe where we have not found upstream gallery. The impact of trepanation of the two solution pipes makes it illusory the study of fissures upstream of the pt. 43, which is 421 m from the entrance (Rodet et al. 2009). As a result, we limited our study area between the pt. 1 (entrance) and the pt. 43.

From this topography, we carried out a campaign of systematic survey, *in situ*, of (i) the orientation of the

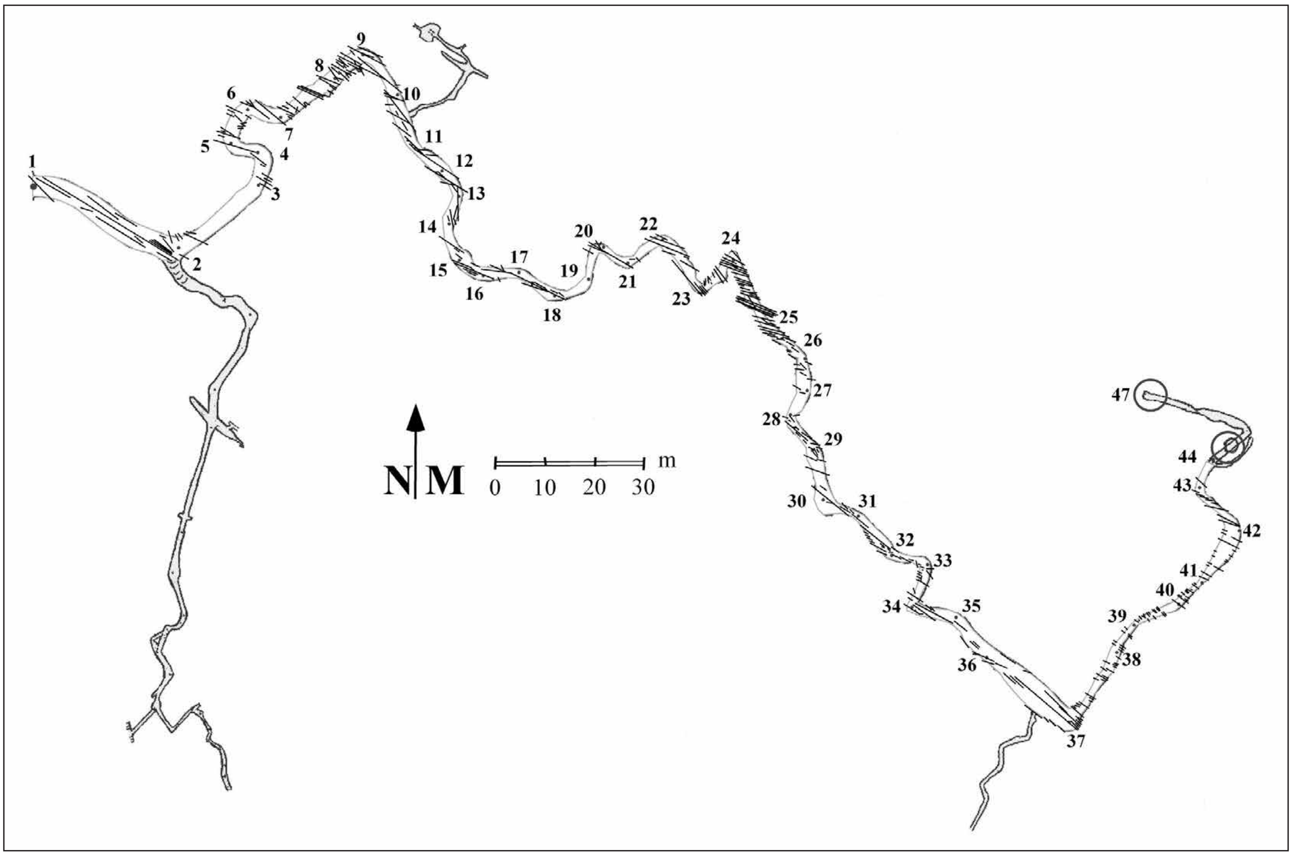

Figure 2. Survey of the Petites Dales Cave, with the tectonic network.

sections of the collector, (ii) the length of these sections, (iii) the orientation of visible fissures in the roof and the walls of the sections, (iv) the length of the fissures. Every joint was oriented (az degree) and measured with a tape measure. For fissures in the form of broken line or curve, we measured the orientation between the two extreme points. Each joint was numbered and plotted on the spot on a 1/100 topographic map. The measures were then introduced into a spreadsheet. By combining these data, we can define drain / joint relation models to assess the impact of visible tectonics on the karst development, and the impact of hydraulic gradient supported by the porosity of the bedrocks.

The first element to consider is the spatial organization of the 42 segments which compose the drain being studied, according to their orientation and accumulated length of development by azimuth class. The second element is the tectonic network survey, according to its frequency, directional distribution and accumulated length of development by class. Finally, the comparison of the two types of data aims to understand the relationship between tectonics and karst drain under discussion.

As indicated by the reference point pt. 43, the 42 oriented segments of gallery were grouped by class of 5° (Fig. 3a). The 374 inventoried joints were grouped according to their magnetic orientation (az value) by class of five degrees.

3. Results

The cavity was examined along the 421 m of the drain. 374 joints, with a total length of 867.70 m of fissures (f), were identified.

3.1. Collector directions

The distribution of the 42 directions is very dispersed: no class contains more than 4 sections and thus reaches 10 %. It is relatively uniform across all classes, with a slight concentration in two large sets (11–70° and 106–155°), in the middle of less relevant values.Concerning the cumulative length of the conduits (Fig. 3b), two sets are slightly reinforced. The first set is bipolar with a first peak around 11°/15°, a second around 31°/50°, and more specifically between 40° and 50°, clearly in SW/NE direction. The second set is more uniform with a maximum in the 136°/140° Class, the maximum being further accentuated as to the cumulative of NW/SE segment lengths.

Both directions, and especially values between 120° and 150°, correspond to lineaments and faults of the Pays de Caux (Hauchard et al. 2002, 2008).

3.2. Joints in the collector

The output gallery is marked regularly with topographic stations used as a benchmark to locate oriented gallery segments and fissures identified in the roof and the walls of the gallery. The total development of drain is 421 m (420.90 m), in which 374 joints are identified with a total fissure length of 867.70 m. Thus, the average length of fissure is 2.32 m, the number of fissures per linear meter of drain is 0.89, and the length of fissure (mf) per meter of drain is 2.06 m.

For morphological reasons (Fig. 2), we divided the main gallery into four sectors, namely:

3.2.1. From pt 01 to pt 11

In this first sector, the length of conduit is 119.30 m, which represent 28.34 % of the total length of gallery. We identified 101 joints or 27.1 % of all fissures identified throughout the gallery. We obtain a density of 0.85 fissure per meter of gallery. The total length of joints rises to 336.80 m, which means a ratio of 2.82 m of fissure per meter of drain.

3.2.2. From pt 11 to pt 24

In this second sector, the length of conduit is 100.80 m, which represent 23.95 % of the total length of conduit. We identified 67 joints, or 17.91 % of all fissures identified throughout the gallery. We obtain a density of 0.66 fissures per meter of gallery. The total length of joints rises to 196.10 m, which means a ratio of 1.95 m of fissure per meter of drain.

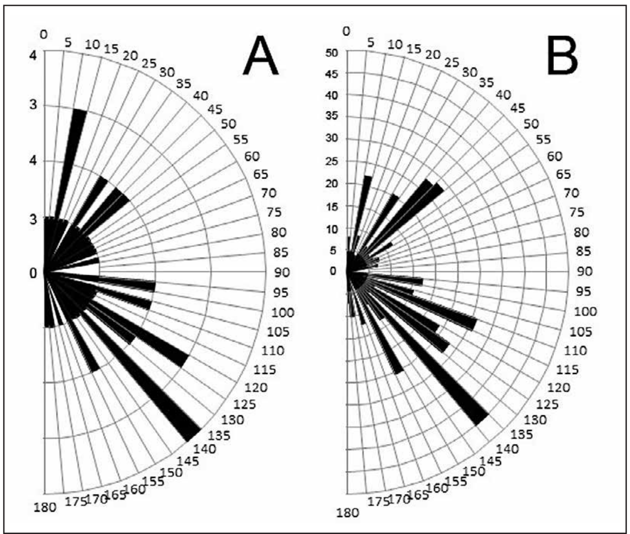

Figure 3. Distribution of the segments in the main gallery. A: number of segments by 5° sets. B: cumulative length of the segments by the same sets.

3.2.3. From pt 24 to pt 37

In this third sector, the length of conduit is 136.40 m, which represent 32.41 % of the total length of conduit. We identified 118 joints, or 31.55 % of all fissures identified throughout the gallery. We obtain a density of 0.87 fissure per meter of gallery. The total length of joints rises to 267.50 m, which means a ratio of 1.96 m of fissure per meter of drain.

3.2.4. From pt 37 to pt 43

In fourth sector, the length of conduit is 64.40 m, which represent 15.30 % of the total length of conduit. We identified 88 joints, or 23.53 % of all fissures identified throughout the gallery. We obtain a density of 1.37 fissures per meter of gallery. The total length of joints rises to 67.30 m, which gives a ratio of 1.05 m of fissure per meter of drain.

3.2.5. Summary of all sectors

There is therefore a medium density of joints in the first sector (0.85 f/ml). It falls in the second sector to 0.66 f/ml, returns to the average of the first sector in the third sector (0.87 f/ml), and increases significantly in the fourth sector (1.37 f/ml).

We also note that the joint density is not in the pair with the joint length, since the ratio decreases from the entrance to the end where the lowest ratio (1.05 mf/ml) accompanies the highest fissure density (1.37 f/ml). Only in the two intermediate parts the overall average is approached. Is this increasing ratio from the end to the entrance reflecting a possible relaxation effect of the massif induced by the opening of the Petites Dales Valley?

3.3. The directions of joints

They are 374 inventoried joints grouped according to their magnetic orientation (Fig. 4). There is an overwhelming concentration of orientations between 100° E and 145° E. The rest is trivial: a small class of 15–20 ° and an even smaller one near 180° (Fig. 4a). This NW/SE orientation dominance is even stronger. It concentrates around 115–125° when we focus not on the number of joints but their cumulative development (Fig. 4b).

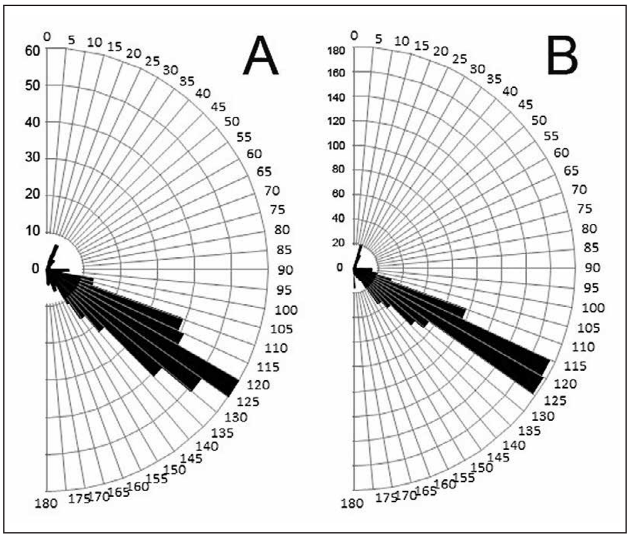

Figure 4. Distribution of the fissures in the main gallery. A: number of joints by 5° sets. B: cumulative length of joints distributed in the same classes.

4. Discussion

What do the results mean?

4.1. Drain/joint directional relations

The relations between the direction of the drain and the joints reveal four cases.

4.1.1. The joints accompany or frame the drain

We can suppose that there is a relationship between joint and drain, as a lot of studies shows in numerous conventional caverns in limestone with low permeability or porosity (White, 1988). Certainly the combination of fissures and hydraulic gradient provides the best conditions for the development of karst. In the main gallery, it represents 148.4 m, therefore 35.26% of the gallery.

4.1.2. The joints intersect obliquely the drain

The joints intersect obliquely the drain without thereby deviating the gallery. We must therefore conclude that the oblique fissures do not affect directly the conduit. In the collector, it represents 130.2 m and therefore 30.93% of the gallery.

4.1.3. The joints intersect perpendicularly the drain

The joints intersect perpendiculary the drain without impacting the morphology of the walls. Joint does not influence the flow. As in the previous case, only the phases of flooding with a very reduced flow speed affect the morphology of the drain by the establishment of equilibrium chimneys. In the collector, it represents 86.8 m and therefore 20.62% of the gallery.

4.1.4. The joints are absent from the drain

In the collector, there is no joint along 55.5 m, that is to say, 13.19% of the gallery has no relationship with tectonics (Fig. 5).

In total, 365.40 m of the gallery exhibit fissures in the ceiling or walls, that represent 86.81% of the total length of the collector, but in which only 148.4 m, or 35.26%, show a clear relationship between tectonic and karst drain.

We conclude that tectonics is not the only responsible for the establishment of all sections of the collector. Other factors involve either stratigraphy (favorable interbedding) or porosity (with direct impact of the hydraulic gradient). Some authors, supporters of the "all tectonics", suggest the existence of a network of micro-cracks, unproven to date: curiously this network should be large enough to guide the drain, but at the same time it would not be revealed by the flooding phases…

4.2. Drain and joint

The last approach was made by comparing the drains and joints. It shows significant disparities, where there are areas with many joints or significant accumulated metrics of joints, and areas almost without joint. We have established a ratio between length of joint (mf) and length of gallery (mlg), which reveals three classes, depending on whether the ratio is close to the average ratio of the cavity, higher, or on the contrary, lower:

4.2.1. Gallery with a low ratio of fissure

The ratio is low (<1 mf/mlg). 11 of 42 sections provide a ratio of less than 1 m of fissure per lineal meter of drain. This represents 26% of the sections.

4.2.2. Gallery with a ratio close to the average

The ratio is close to the average of joint (2.06 mf/mlg) of the whole gallery, between 1 and 3 m of fissure per meter of drain. This represents 25 of the 42 sections of the collector, i.e. 60% of the sections.

4.2.3. Gallery with a strong relationship to tectonics (>3 mf/mlg)

Only 6 sections provide a ratio greater than 3 between the meter of fissure and the linear meter of the gallery. Those sections represent 14% of the segments of the collector. Strangely, the sectors with a high ratio of fissure are those which were strongly influenced by episodes of significant flooding associated with sudden and torrential floods from the downstream solution pipe (pt. 44). Therefore, it relates to the morphology after the establishment of the drain collector, thus the tectonic factor cannot be applied as a determinant factor to the morphogenesis of the former drain.

Figure 5. Segment of the main gallery of the Petites Dales, without joint, between pt. 2 and pt. 3 (photo by D. Guillemette).

The last graphic (Fig. 6) oppose the cumulative length of drains grouped into orientation classes by 5° to the cumulative length of fissures, which are also grouped by class of 5°. There is a wide difference in the distribution of the orientations between the development of drains and the development of joints. In particular, note that while the cumulative lengths of conduits (classes 116–120° and 121–125°) are from 7 m to 24 m, giving a ratio of 3.5, the cumulative lengths of joints are equal (175.9 m and 177.2 m), giving a difference of 1.3 m or a ratio of only 1.007.

Moreover, it should be noted that values equivalent to the linear meters of drains (24 m for 121–125°, and 28 m for 41–45°) are completely opposite to the those of joint (177.2 m and 2.1 m), i.e. a ratio of 84. The lack of relationship between classes of drains and those of fissures, shows very clearly in this case that the development of drains does not depend on the tectonics of bedrock, but on other speleogenetic factors and constraints which must to be identified.

5. Conclusion

The collector of the Petites Dales Cave offers several sectors without joint (Fig. 5). Sections where there are oblique (Fig. 7) or perpendicular joints which do not affect the morphology of the collector drain are not linked to the structure of the bedrock. It is only in the presence of joints / drain correlation that tectonics can be considered with

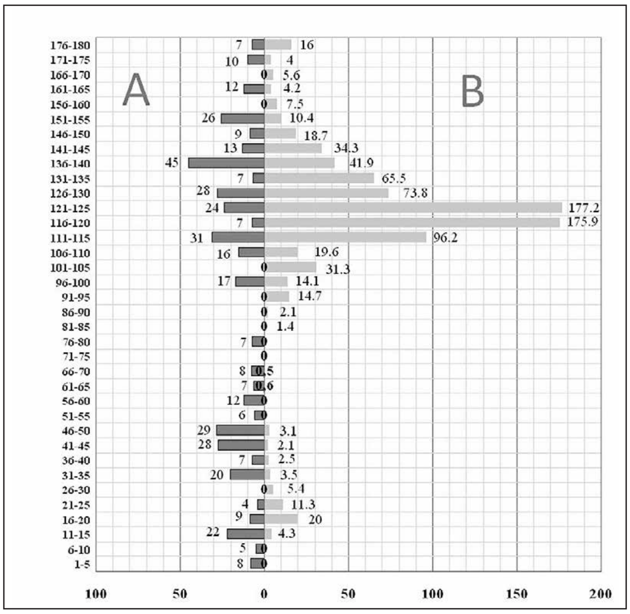

Figure 6. Dual graph of distribution by class of orientation (5°). A: cumulated length of the segments in the main gallery. B: cumulated length of the joints observed in the main gallery. We note the absence of correlation between A and B.

certainty to affect the karstification. In theory, it is one out four cases. Concerning the development of collector of the Petites Dales Cave, it represents less than 150 m of the drain, that is to say, just over 35% of the main drain.

Clearly, porosity, by allowing the dispersion of the flow, promotes the expression of the hydraulic gradient. This dimension reduces, sometimes even annihilates the impact of the structure. Thus, it is in the phases of saturating flooding, when the flow velocity is minimized by effect of damming, that the weaknesses of the bedrocks manifest, especially through joints.

As a result, the correlation or the non-correlation between the direction of the drains and the structure of the bedrock reflects the impact of bedrock on drains. For a long time, chalk was compared to a sponge and thus the existence of karst within it was denied. Today, no one denies any more the obvious, but the chalk, porous limestone, has its specificities, both morphologically and hydrologically, which are shown by the development of the karst.

References

Hauchard E, Laignel B, Delahaye D, 2002. Proposition d'un nouveau schéma structural du Nord-Ouest du bassin de Paris reposant sur l'analyse fractale de la morphologie des réseaux de thalwegs et les données récentes de la géologie régionale. C. R. Geoscience, 334, 295–302.

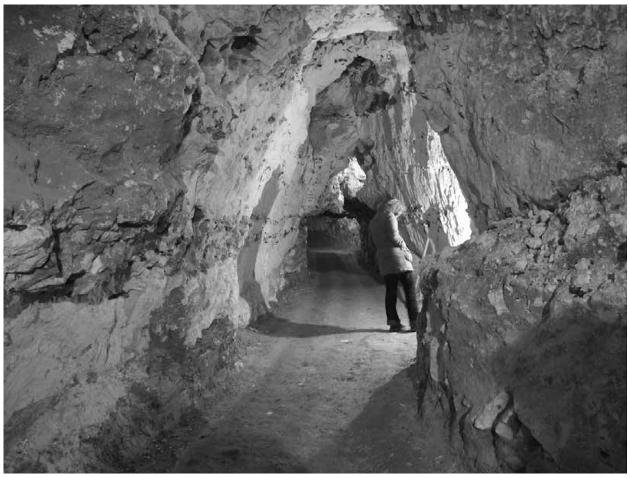

Figure 7. Segment of the main gallery, with obliquily intersection of joints, between pt. 24 and pt. 25 (photo by J. Rodet).

Hauchard E, Laignel B, 2008. Evolution morphotectonique de la marge nord-occidentale du Bassin de Paris. Zeitschrift für Geomorphologie, 52 (4), 463–488.

Jakucs L, 1977. Morphogenetics of karst regions – variants of karst evolution. Adam Hilger, Bristol: 284.

Laignel B, Dupuis E, Rodet J, Lacroix M, Massei N, 2004. An example of sedimentary filling in the chalky karst of the Western Paris Basin: Characterization, origins and hydrosedimentary behaviour. Zeitschrift für Geomorphologie N.F., 48 (2), 219–243.

Rodet J, 1992. La craie et ses karsts. Ed. Groupe Seine CNRS Caen & CNEK, Elbeuf, 560.

Rodet J, Laignel B, Dupuis E, Brocard G, Massei N, Viard J-P, 2006. Contribution of a sedimentary study to the karstic evolution concept of a chalk cave of the Western Paris Basin (Normandy, France). Geologica Belgica, 9 (3–4), 287–296.

Rodet J, Viard J-P, Poudras J, 2007. A la découverte de la grotte des Petites Dales (Saint Martin aux Buneaux, Seine Maritime, France). Spéléo-Tract, 6, 38.

Rodet J, Viard J-P, 2009. La grotte des Petites Dales, un patrimoine normal? non! normand! Spelunca, 114, 28–34.

Rodet J, Willems L, Brown J, Ogier-Halim S, Bourdin M, Viard J-P, 2009. Morphodynamic incidences of the trepanning of the endokarst by solution pipes. Examples of chalk caves in Western Europe (France and Belgium). Proceedings of the 15th International Congress of Speleology, Kerrville (Texas, USA), 19–26 July 2009, UIS, vol. 3, contributed papers: 1657–1661.

White WB, 1988. Geomorphology and hydrology of karst terrains. Oxford University Press, 464.