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The primokarst, former stages of karstification, or how solution caves can born

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ABSTRACT. The historical approach of the karst always gave preferential treatment to the study of the superficial phenomena or underground cavities explored by human. However as demonstrated by hydrogeologists, the main karst development keep out of reach because of the too small sizing of drains or due to its filling. Consequently appears the question about the inception drain, the way used by the water from the sink hole to reach its resurgence. Some authors consider this primary link as obvious when the practice demonstrates clearly that the hydrodynamic continuity results of a very long, complex and selective evolution, essentially geochemical. This is the field of the drain inception stages, that we can spell "prekarst" or "primokarst". Those stages include the successive fields of isalterite and alloterite. This last one opens by compaction a free space and allows a concentrated hydrodynamic flow. These processes, at the origin of the endokarst initiation, can develop on the side of synchronous mechanical dynamics if in the same drain or under a regolith coverage, something divides the bedrock and the quick flow. Without any doubt, this is the purview of the cryptokarst and of the cave walls under filling. We can observe it in the progradation front of the introduction karst or in the retrogradation front of the restitution karst.

KEYWORDS: karst inception, weathering front, introduction karst, restitution karst, hydrodynamic link, inception stages

RESUME. Le primokarst, phases initiales de la karstification. Pour des raisons historiques, le karst et ses expressions ont toujours été abordés depuis la surface ou au travers des cavités souterraines explorées par l'homme. Cependant, comme l'ont démontré les hydrogéologues, l'essentiel du développement karstique reste inaccessible en raison de la dimension trop réduite des drains ou de leur remplissage. Se pose aussi la question du premier drain, celui qu'emprunte l'eau entre la perte et sa résurgence. Certains considèrent cette liaison fondamentale comme évidente, alors que l'expérience démontre très largement que cette continuité hydrodynamique est le résultat d'une très longue, complexe et sélective évolution essentiellement géochimique. C'est le domaine des phases de préparation des drains, en quelque sorte du «prékarst» ou «primokarst». Ces phases couvrent les domaines des isaltérites auxquelles succèdent les allotérites qui, par leur tassement, libèrent l'espace nécessaire à l'écoulement concentré de l'eau et autorise la mise en place de l'hydrodynamisme. Ces processus, fondamentaux à la naissance de l'endokarst, peuvent accompagner d'autres dynamiques plus mécaniques, dès lors qu'un milieu opposé à l'écoulement rapide se développe dans un drain ou sous une couverture meuble. C'est sans conteste, le domaine du cryptokarst et des parois contre remplissage. On peut l'observer dans les fronts de progression du karst d'introduction, ou de régression du karst de restitution.

MOTS-CLÉS: karst initial, front d'altération, karst d'introduction, karst de restitution, liaison hydrodynamique, phases initiales

1. Introduction

For the last decades, the multidisciplinary approach of karst leads to two great theories about the settlement of the underground solution cavities (Bosák, 1989; Klimchouk et al., 2000). The first and most classic one deals with caves that are developed from superficial waters (Jennings, 1971; Ford, 2004; Ford & Williams, 2007), according to two opposite hydrodynamic systems that are sum up in two names: "input karst" or "karst of introduction" and "output karst" or "karst of restitution" (Rodet, 1981, 1992). These caves can be classified as exogenous, those that appeared from the superficial water introduced into the substrate (Jones & White, 2012; Palmer, 2007, 2012; Williams, 2004). The second one, far less taken into account, concerns caves that have developed from deep waters, either those included in a long regional journey, or from thermal waters, and can be qualified as endogenous (Klimchouk, 2012; Palmer & Palmer, 1989; Stafford et al, 2009).

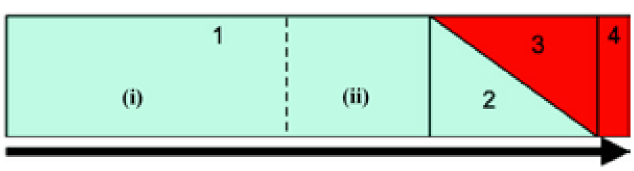

Figure 1. Conceptual model of the evolution of the karstification in process and time, from the former or incipient stages (only chemical weathering) to the syngenetic dynamics - (hydrodynamics). 1- the primokarst, with two main and successive stages: first the isalterite (i) and second the alloterite (ii), 2- the opening of the alloterite complex gives way to hydrodynamics, first to the paragenetic dynamics, 3- and slowly, flowing from paragenetic dynamics to syngenetic dynamics with transport of solid particles, 4- until, sometimes, the syngenetic dynamics, with elimination of solid particles and mechanical erosion. The arrow represents the time passing, showing the great disequilibrium between each stage. If the hydrodynamic stages can be realized in a very short time, always, the primokarst stages result of a very long time.

In this paper, the study only concerns the first case, of exogenous solution caves (Gabrovšek, 2012; Jennings, 1985).

In the classical conception of karstification, the notion of hydraulic junction between the inlet and outlet of water is an acquired fact, because the water finds its way through the mass thanks to structural discontinuities in the massif (Bögli, 1980). Choppy (1994: p. 5) writes "karstic digging is only made possible by circulation". But what does he mean by "circulation"? Does it deal with a substratum imbibition or with a concentrated flow in the mass?

The preparation of the water flow in the mass leads to the notion of hydraulic continuity solution, and takes a huge part in the most random and complex phases, that are nevertheless essential to the realization of a karstic system. Concretely, the surface only shows the cross-checking of the system by topography whereas the underground exploration only allows to access the biggest volumes, that are not necessarily the most significant to speleogenesis (Fig. 1). As a consequence, researchers have got only interested recently to the preparation phases of the karst because these ones are by definition non-reachable by the classic ways (Devos et al., 2011; Dubois et al., 2011; Havron et al., 2007; Quinif, 2010).

2. Initial drain and dichotomy of the water traveling

From Antiquity to nowadays, theories about the origins of the caves are numerous (White, 1988), but despite their complexity which becomes more and more important each time, none of them takes into consideration the problem of the process of realization of the first duct. Karstologists, and maybe even more hydrogeologists, only consider karst as a research topic from the moment when the relation between loss and resurgence is done. Nevertheless when we think about the first duct, the one which allows an hydrodynamic junction, scientific literature remains quiet. For a long time, it has been said that water found its way

Figure 2. Lago Azul Cave (Cuiabá, Mato Gosso, Brazil). This former ponor is working today as an emergence due to the piracy of the polje by an epigeous river valley (photo. by J. Rodet).

through the mass, using the discontinuities and the weaknesses of the substratum. Thus, Gèze (1966: p. 30) lays the emphasis on the fact that "in order to allow the massive sinking of rivers, or even the accelerated infiltration of heavy rain, the initial cracks (stratification, joint, fault) have to enlarge gradually by the physical and chemical action of this water. Erosion is the mechanical phenomenon which causes this enlargement. Of course it supposes that water already flows with a certain violence and that it is only possible with an important quantity of water flowing down to an output feature that is already largely wide open itself."

In fact, that we ignored, because we almost never observed it, is that water creates its way little by little, until it succeeds in connecting hydrologically introduction and restitution.

Without such a junction, we can observe two mechanisms linked to the two possibilities for the water to get through a massif: upstream, from the surface, the input which can be called "introduction karst", and downstream from the valleys, the output which can be called "restitution karst" (Rodet, 1981).

2.1. The progression of a weathering front (prograding)

The progression of water in the introduction karst is in fact a slow progress of the alteration front into the mass of the substratum

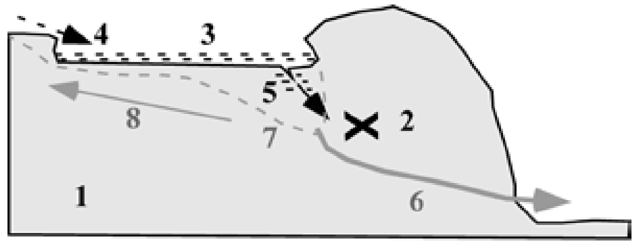

Figure 3. Polje and doline. First stage - the polje: 1- massif, 2- underground dam (without input/output connection), 3- formation of a polje, 4- input water, 5- ponor or underground reservoir. Second stage - the doline: 6- input/output linking, 7- opening of a doline, 8- transformation in a blind valley (regressive erosion).

(prograding). Its structure, and in particular its fissuring, can lead this progress, but in porous bedrock, this forcing can be totally inoperative (Willems et al., 2007). If the downstream does not allow the flow, insoluble and decayed particles load the weathering front, helping in slowing its progression.

This progression can be condensed in four points: (i) the settling of a overburden screen, (ii) the development of solution pipes or "roots of the weathering mantle" and the cryptokarst, (iii) the basal opening in contact with the aquifer, (iv) the trepanation of a restitution drain with the hydrodynamic junction (Willems et al., 2007).

This is classically observed in the sub-vertical solution pipes, but also in sub-horizontal to slightly steep complex caves (Fig. 2), as Aroé Jari (Mato Grosso, Brazil), where the input galleries are composed of chambers whose walls are completely altered (Hardt et al., 2013).

Besides the congestion by decayed particles there is also the question of the renewing of the geochemical acuity of the water, and also the removal of elements in solution. This explains the slowness of the process. The most obvious example of this situation could be the swallow holes of poljes (ponors or estavelles) that offer only very rarely significant developments (Jakucs, 1987; Jennings, 1985; Nicod, 2003).

A polje indeed develops due to the inability of the introduction karst to absorb hydrologic excesses (Herak, in Herak & Stringfield, 1972: 25-83; Milanovic, 1981; Dufaure & Vaudour, 1984; Bonacci, 2004a). Once the hydrodynamic connection is realized between input loss and resurgence, the polje can be pierced by one or more sinkholes while it dries slowly (Bonacci, 1987, 2004b) (Fig. 3).

Figure 4. Grasteau partial cross section: alterite of limestone with aspect of ghost-rock (La Mansonnière, Normandy) (photo. by J. Rodet).

sample	location (cm)	montm /quartz	% calcite	% quartz	% opal	SiO2	Al2O3	Fe2O3	MgO	CaO	K2O	Na2O	TiO2	MnO	H2O-	H2O+
A0	-5					17,94	1,03	0,67	0,60	43,51	0,21	0,08	0,02	0,01	0,70	35,16
A1	0					20,65	0,77	0,74	0,55	41,50	0,43	0,02	0,02	0,02	0,77	34,20
A2	5,5	2,4	4	37	59	71,18	7,45	4,45	1,00	2,36	0,96	0,23	0,23	0,03	5,61	5,52
A3	14	3,5	0	17	83	73,44	7,15	4,17	0,92	1,64	0,89	0,16	0,16	0,01	5,76	4,78
A4	20	2,2	0	31	69	76,09	6,77	3,92	0,90	1,02	0,86	0,14	0,14	0,02	5,57	4,45
A5	30	6,0	7	75	18	56,78	13,96	6,73	1,68	1,36	1,56	0,58	0,58	0,02	10,10	6,54
A6-	50	4,6	0	21	79	79,71	5,32	2,97	0,70	0,76	0,83	0,12	0,12	0,01	5,04	3,30
A6+	51					81,08	4,94	2,58	0,60	0,72	0,85	0,15	0,15	0,01	4,57	2,98
A7	72	6,3	13	34	53	66,41	10,79	5,36	1,23	1,35	1,38	0,41	0,41	0,02	7,45	5,34
A8	82	6,4	28	23	49	72,97	7,95	4,50	0,90	0,98	1,04	0,32	0,32	0,03	6,48	4,69
A9	106	24,5	0	25	75	73,61	7,76	4,49	0,90	1,03	1,02	0,11	0,28	0,03	6,14	4,40
A10	430	16,6	69	6	25	66,42	10,43	5,79	1,14	1,42	1,45	0,14	0,39	0,07	6,77	5,66
A11	163	0,0	65	35	0	67,12	10,00	5,42	1,10	1,42	1,47	0,15	0,42	0,08	6,07	5,47
A12	203	2,8	0	22	78	83,80	4,45	2,58	0,50	0,82	0,71	0,10	0,11	0,03	3,81	2,91
A13	211	6,0	0	53	47	66,35	8,75	5,25	1,20	2,68	1,61	0,12	0,28	0,03	7,20	6,16
A14	223	4,2	0	37	63	63,37	5,56	3,26	0,79	8,16	1,06	0,11	0,23	0,03	7,91	9,00
A15	238					22,65	1,35	1,04	0,6	39,3	0,40	0,06	0,04	0,02	1,11	32,86

Figure 5. Geochemical analysis of the Grasteau cross section samples (see Fig. 4). Monim: montmorillonite. Relation between montmorillonite main peak x10 and quartz main peak (analysis by A.V. Walter-Simonnet).

2.2. The regress of an alteration front (retrogressive erosion)

The increase of water flow in a restitution karst is defined by the regress of the point of water extraction of the rock mass resulting in retrogressive erosion. Due to the unobstructed drainage, the flow allows direct discharge to the output emergence of the mobile insoluble and decayed particles (relation size / flow rate) and it lets the alteration front cleansed of its decayed particles. Upstream in the Lapa do Triangulo (Serra da Piedade, Brazil), the sands coming out the banded iron formation and ironstone outcrops (itabirite) make a mark on the ground due to the flows in the rainy season (Pereira et al., 2012, 2013). We can observe the same mecanism in the Quentin cave (Belgium) under anthropogenic influence (Quinif & Maire, 2010).

Two evolution phases have to be kept in mind: the one which accompanies the decline of the supply front which is sometimes divided according to heterogeneous contributions from the bedrock, and the one of the cross-checking of an introduction drain (Rodet et al., 2009a), which is sudden and spectacular (Bauer, 1989) and establishes the hydrokarstic junction.

3. The "primokarst" concept

The primokarst concept was defined as "an illustration of the first evolution stages of the karstification", during the 3td European Congress of Speleology, at Lisbon, in 1999 (Rodet, 1999b; Nicod, 2002). The concept results of a lot of observations in karst areas all around the world, but it is the discovery of the Mansonnière site, in Normandy, responsible for its concretization. This concept of earliest stages of speleogenesis does not have any connection with the "Inception Horizon Concept" of Lowe (Lowe, 1992, 2000, 2004; Lowe & Gunn, 1997; Filipponi & Jeannin, 2009).

3.1. Observations

The first observations were realized in the Mansonnière Cave (Orne, France) in 1993 (Rodet, 1996). Over 1000 m of karstic galleries blocked by terrigenous and non-consolidated elements were investigated in a mesh network. Unclogging activities allowed an identification of these elements, not as alluvial deposits but as *in situ* saprolite (Rodet, 1996, 1999a). Mineralogical and chemical analysis realized in various cross sections, proved a sub-vertical organization linked to the tectonic network. 15 terrigenous samples were collected in the gallery n° 15, named Grasteau (Fig. 4), in a 2.38 m wide cross section (Fig. 5).

That was first considered as filling is in fact the result of the accumulation of most of the residual elements of the dissolved chalk, with an important decrease of the CaO, more Al_2O_3 and TiO_2 and the leaching of part of Fe and Si. The analyses show a movement of autochthonous terrigenous material to fill the karstic void as chalk only contains about 1 % of Al_2O_3 and 20 % of SiO_2. This is not enough to explain such thick quartz clay fillings. The alterite is an *in situ* accumulation of residues from dissolution, and secondly that comes from above (illite, Al_2O_3, TiO_2) even if there is some leaching of Fe and Si.

The mineralogical composition is mainly residual calcite, quartz and opal, and in the clay group: montmorillonite and illite, the latter comes from the Sables du Perche Formation. The absence of the Sables du Perche Formation today in the site shows that it was covering the area during the weathering operation of tectonic axes.

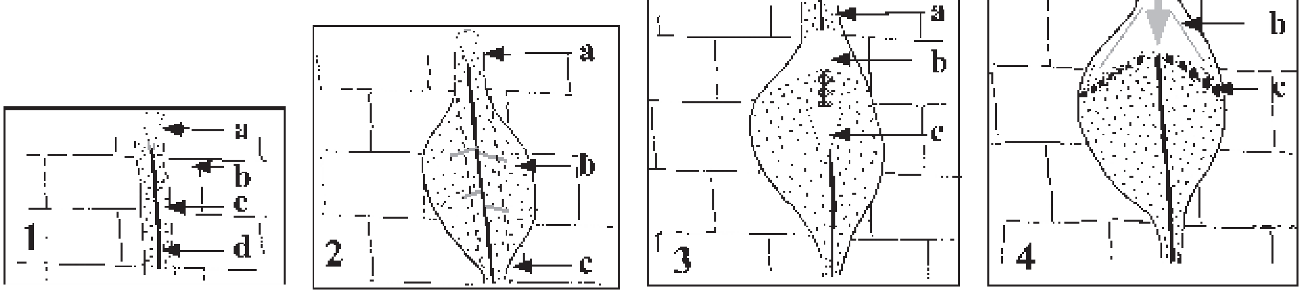

Figure 6. 1. Primokarst first stage: weathering of a (tectonic) axis. a: feeding of the individualized weathering front; b: bedrock; c: weathered bedrock (ghost-rock); d: tectonic axis materialized by a smectite string. 2. Primokarst second stage: local enlargement of the (tectonic) axis. a: feeding of the individualized weathering front; lateral diffusion by percolating; c: underground water base level. 3. Primokarst third stage: breakdown of the weathering complex and air opening. a: feed cessation of the weathering front; b: air opening void; c: packing of the alterite skeleton (from isalterite to alloterite). 4. Primokarst fourth stage: the first introduction of a karstic flow. a: sporadic feeding of the weathering front; b: exogenic particulate input; c: displaced clay polyhedra.

Since then, observations have increased in many caves in various latitudes, in various substrates, carbonated and non-carbonated, in Europe and in America at least. These observations show that the primokarstic processes are also active in mature karst drains. The shapes of the walls, behind the saprolite are the same as those identified in karst drains with low hydrodynamic energy, often crowded with sedimentary deposits (paragenetic dynamics).

3.2. Mechanism of the weathering of a substratum

In the introduction karst four basic stages are defined from our observations. The objective is to define better what happens in the mass, which can lead to the development of a human penetrable karst.

3.2.1. Clearance of an individualized front

This is the stage of a normal vertical progression of the weathered axis, until it reaches the saturated zone. To begin, a clay film develops in the center of this axis, when the bedrock, strongly alterated, recovers slowly its initial qualities into the peripheral mass. In mesh networks of the Perche, the clayed film (smectite) makes concrete the initial tectonic crack and the axis of symmetry of the alteration (sand residuals) (Fig. 6.1).

In the solution pipes, this smectite film develops in periphery, in contact with the bedrock, and the heart is occupied by superficial deposits. The possible presence of superficial formations in peripheral location highlights a more complex multistage evolution.

The alterite resulting of the weathering of the substrate can be spelled "ghost-rock" (Quinif, 1998, 1999; Vergari, 1998).

3.2.2. Lateral expansion and isalterite formation

This second stage is the axial locking of the alteration front that allows a lateral diffusion of the alteration. In porous areas, the diffusion is achieved by percolation into the mass (Fig. 6.2). The alteration is of an isalterite kind (Campy & Macaire, 1989), it means that the skeleton of the bedrock is preserved in its structure and volume, but a significant part of its constituents is dissolved. Evolution is only geochemical and mineralogical. Its consequences are a lateral extension of the altered zone. The only inputs are in the form of salts in solution, as much from the bedrock as from the surface.

3.2.3. The compacting of the alloterite

The third stage is the one of the rupture (Fig. 6.3). Following the increase in voids and porosity, the skeleton reaches its limit of strength and compacts. This mechanism may be associated with the discontinuation of water supply and thus a drying phase of alterite that retracts by water loss from clay elements. The isalterite becomes alloterite (Campy & Macaire, 1989) and the structure of the bedrock is no longer maintained. As a consequence, an airy crescent which amplifies the effects of drying opens on the roof and allows concentrated water intrusion, and also the exogenous particulate supply, and not only dissolved salts anymore.

3.2.4. Exogenic supplies and opening

The opening of the altered space allows the concentrated water intrusion and therefore the establishment of hydrological dynamics associated with the notion of karst (Fig. 6.4). This stage is often a drain restitution trepanation, leading to the solution of hydrological continuity. We leave the field of the mainly geochemical primokarst for the geochemical and hydrodynamic dualities (paragenetic dynamics), which can scale up to the domination of powerful erosive dynamics that are syngenetic.

3.3. Scope of the "primokarst" concept

The primokarst is the expression of early stages of karstification, those who prepare the drain in which the concentrated flow will be formed. All karstic drains from dissolution processes must all have had a primokarstic phase, short or long. But all primokarst expressions do not automatically lead to an active drain. For various reasons, the flow can never be realized. In the Perche Region, the removal of the weathering mantle that concentrated the input waters, is responsible for the abortion process (Rodet, 2007).

Figure 7. Wall alteration under sediment filling or saprolite in a karst gallery - Le Tilleul Cave, France (photo. by J. Rodet).

In Picardy, Champagne and Northern Paris Basin the lack of regolith coverage does not facilitate the concentrated introduction of rainwater in a porous mass, in which the introduction karst is almost absent (Rodet, 1992). On the other hand, it can be questioned if the chasms that open into lapies without catchment basin testify for a former weathering mantle, evacuated by the flow or absorbed by the sinking of the drainage into the substrate. One of the elements necessary to the establishment of a primokarst seems to be a screen cover (Rodet 1993; Lacroix et al., 2000, 2002; Bittencourt & Rodet, 2001, 2002; Jaillet, 2005). The disappearance of this coverage may be the cause of the shutdown of the process.

But the process of primokarst is widespread in the underground. This is the absolute expression of the geochemical alteration (Fig. 5) and the absence of a hydrodynamic effect. Consequently, the expression domain of this process is extended to the whole cryptokarst, including the bottom of the deepest solution pipes or roots of the weathering cover, but also in any active or fossil drain more or less filled (Fig. 7), when a certain moisture filling process allows the alteration process of the walls ("wet compress effect" of Gamez, 1992 ; Zupan Hajna, 2003). In this context, the primokarst is not necessarily an indicator of a primophase of the genesis of the cave, but can be present and active. The wall and/or ceiling karrens are often the expression of such a fact. This mechanism also explains why we can observe a primokarst process in front of an active drain of restitution: in the absence of a connection with the introduction karst, the primokarst expresses in the regressive erosion front, upstream. Weathering processes, whose importance is revealed by the primokarst are the fundamental and former agents of karstification. While they may

Figure 8. The weathering processes transform the upper layers of the limestone bedrock in waterproof clay stopping the vertical water descent (La Mansonnière, Normandy) (photo. by J. Rodet).

Figure 9. Incision of solution pipes or "roots of the weathering coverage" on the surface of the bed-rock, isolating limestone pinnacles near Duclair (Normandy) (photo. by J. Rodet).

seem less important because of their expression, obviously they represent the most important amount of time in the constitution of karst without common measure with the activation time of the hydrodynamics (Fig. 1).

4. Primokarst and the forms of introduction

In the input karst, the primokarst represents the main part of the expression of these processes, as long as the junction with a karstic restitution has not intervened. We can consider three main stages of evolution before the connection.

4.1. Waterproofing of the top of the bedrock

Any exposed rock in the open air undergoes the weathering processes that radically change the qualities of the substrate. The product of this weathering is either evacuated and thus the processes continue, or covers the bedrock and then modifies the interface with the atmosphere. In the first case, we observe a bare karst, in the second it is a covered karst. It then joins the context of a substrate under a movable covering layer, with compositions simple to complex, depending on the local or regional geological evolution. As demonstrated by studies within the UMR 6143 CNRS (Rodet et al., 2009b), under the hydrochemical and mechanical constraints, the top of the substratum can become waterproof (Fig. 8), allowing the development of an aquifer into the overburden (Lacroix et al., 2000).

The mineralization of this upper aquifer can be compared to the one of the waters of the deep aquifer, and demonstrates interactions between the overburden aquifer and the top of the substratum (Lacroix et al., 2002; Brown et al., 2008). This upper aquifer plays a fundamental role in the vegetative cycle, but also in the deep aquifer recharge. The upper aquifer gets lost in the holes that remain, and open in the top of the substratum, allowing a concentrated introduction in the substrate, where forms of introduction to the karst system are developed (Gamez & Sary, 1979; Rodet, 1992). Gamez (1992) attributed to this coverage the function of "wet compress."

Figure 10. Field of n° 1 type solution pipes at the ceiling of the Caster Cave (Dutch-belgian border). We can note the absence of tectonic elements (photo. by J. Rodet).

4.2. The roots of the weathering coverage

Weathering pockets that develop in the substrate, perpendicularly to the waterproof interface holes grow faster than the general weathering front of the massif (Fig. 9). Therefore we called "roots of the weathering coverage" these solution pipes (Rodet, 1981, 1992, 1997). The introduction is realized according to the conditions of the weathering coverage, and the impact of the structure of the bedrock is not always preponderant. This is why the shape often remains circular, despite the overlap of a crack. Under pebbly paleo-terraces, the density of the weathering roots can be very high (Fig. 10) (Willems et al., 2007). If the structure is consistent, the shape points it. The example of the Porte d'Aval at Etretat, France, illustrates the speech (Rodet, 2013): the tube remains circular while it grows along the crack that guides the development of the arch (Fig. 11). Nothing in the observation of the weathering root can consider that the crack is later than karstic digging.

Usually, the examination of the contents of the weathering root reveals a heart made with products from the movable covering layers (Quaternary loess, Tertiary sands…) progressing downwards while the periphery in contact with the substratum, consists in neoformed clays or clays extracted from the enclosing beds, often blackish smectites, sometimes in polyhedra, which

Figure 11. This circular n°5 type solution pipe developed on the joint line of the "Porte d'Aval" Arch (Etretat, France), links the top of the bedrock with the restitution karst (photo. by J. Rodet).

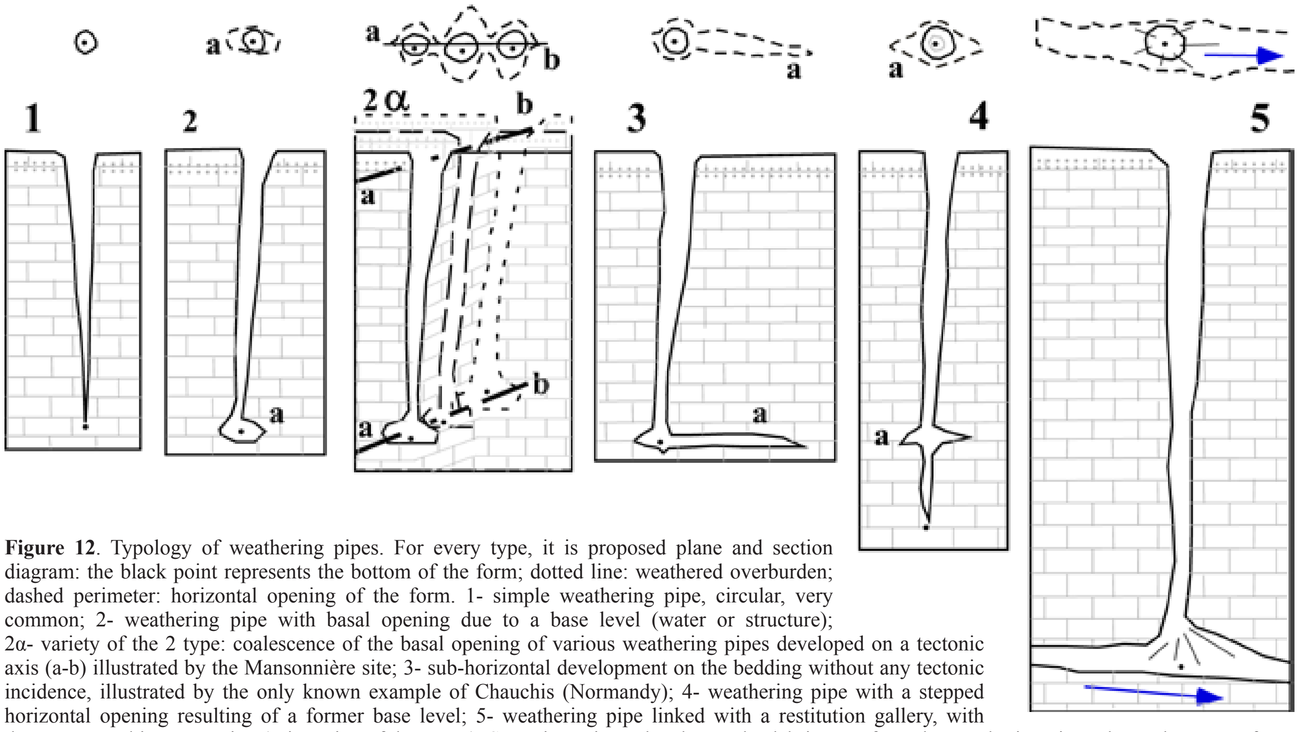

Figure 12. Typology of weathering pipes. For every type, it is proposed plane and section diagram: the black point represents the bottom of the form; dotted line: weathered overburden; dashed perimeter: horizontal opening of the form. 1- simple weathering pipe, circular, very common; 2- weathering pipe with basal opening due to a base level (water or structure); 2α- variety of the 2 type: coalescence of the basal opening of various weathering pipes developed on a tectonic axis (a-b) illustrated by the Mansonnière site; 3- sub-horizontal development on the bedding without any tectonic incidence, illustrated by the only known example of Chauchis (Normandy); 4- weathering pipe with a stepped horizontal opening resulting of a former base level; 5- weathering pipe linked with a restitution gallery, with downstream a bigger opening (orientation of the arrow). Sometimes, it can be observed a debris cone from the weathering pipe. The coalescence of two weathering pipes give the same evolution with invasion by the debris of the first pipe into the second, if the last one is previously empty.

have sub-vertical sliding surfaces slip, indicating stages of compaction and sudden slipping (Rodet, 1992). More rarely, peripheral cracks are invaded by loess.

In its worst advanced stages, the solution pipe has a cone shape with its tip downwards, that in accordance with Choppy (1994: p. 7), would be induced by the loss of aggressivity of the water introduction (Fig. 12, n° 1). Then, when it deepens, it gets a regular section, sometimes tens of meters deep. This well form precedes and accompanies the development of a new stage, when it is in contact with the local or regional base level (Fig. 12, n° 2 and 3).

But the form of alteration in the introduction is not limited to the vertical descent. Especially in some poljes, we can examine ponors with an almost horizontal development, which are only prograding alteration fronts. This is particularly the case of Chapada dos Guimarães caves (Mato Grosso, Brazil), where karstic breakthroughs in silicate sandstones offer exceptional illustrations of these alteration fronts. Chambers in a cul de sac, which are downstream the network, develop within a large residue of weathered rocks. Further upstream, trepanation allowed the drainage and grading of the drains connected to the collector (Hardt et al., 2013).

4.3. Contact with a base level

When the introduction water reaches a base level (whether local or regional), the geochemical movable potential gets laterally to the vertical transit (Fig. 12, n° 2), opening the axis in contact with the base level (Fig. 12, n° 2α). The most striking example is the Mansonnière (Bellou sur Huisne, Orne) (Rodet, 1996). The solution pipe can be transformed gradually into a more consistent volume, but crowded with residues of alteration and elements trapped in the surface. In the Pays de Caux, we have identified some that are more than 80 m deep (Fig. 11). It is conceivable that in mountainous regions, they can reach several hundred meter deep. Certainly, some alpine potholes are ancient solution pipes drained through a drain connection with their restitution.

4.4 The trepanation of a restitution drain and / or an endogenous vacuum

The trepanation of a restitution gallery by a weathering root is a catastrophic phenomenon (Fig. 12, n° 5), very common but really not discussed in the literature (Rodet et al., 2009a). We can consider three cases: (i) the trepanation of an endokarstic alveolus without solution of hydrodynamic continuity, (ii) the trepanation of a fossil drain and (iii) the trepanation of an active drain (Fig. 13). The latter is well known by speleologists who do not generally pay attention to it, focused on the discovery of the main gallery and its river, because few sinkholes and karrens in the lapies give access to the underground Grail.

Whatever the drain hit, trepanation is always catastrophic in its suddenness and the liquid volume introduced into the basal drain. Rarely, the drain can absorb the volume placed downstream, which generates flooding, retention and reascent of fluids. The accident in Achama Lecia, at the Pierre Saint Martin in 1988, is a tragic illustration of this evolution (Bauer, 1989). In the active drain after the dam of the flow, the input is removed gradually. In the fossil drain, a half tube ceiling absorption may develop and often digs underground tank (equilibrium chimneys). The contrast is even stronger in a volume not connected with the outside (Rodet et al., 2009a). In a global way, the contact between introduction and restitution gives an adaptation morphology and an amplified volume (Rodet et al., 2013).

Figure 13. Trepanation of a restitution duct by a solution pipe. The saprolite of the weathering front invaded the restitution gallery (Petites Dales cave, Normandy). In the center, the CWF (clay-with-flints) and on the two sides, the chalk wall with the solution morphology (photo. by J. Rodet).

As a consequence, the hydrological continuity is acquired, the stock of alterite and exogenous sediments can be evacuated and the duct calibrated by the drainage. We leave the field of primokarst to reach certain stages of karstic development with its hydrodynamic regimes (Fig. 1), from paragenesis to syngenesis (Renault, 1967-1969).

5. Conclusion: New concept, old processes

For a long time, the question of the first conduit was evaded, geomorphologists, hydrogeologists and speleologists only considering the karst once the solution of hydrological continuity was established (Ford & Williams, 2007). Primokarst illustrates the geochemical processes of the preparatory phases to the concentrated flow in what has to be called karstic drains. It is also not pseudo-endokarsts but prekarsts. Their observation today is either ongoing process, or a failed development, including the cessation of supply. These processes are not specific to primokarst, insofar as they allow the solubilization of the walls of active or fossil drains, when they host wet terrigeneous deposits (Zupan Hajna, 2003)

Primokarst illustrates the initial stages which lead to the concentrated flow in the exogenous karst. It is particularly observable in its introduction forms, the cryptokarst, as much if the hydraulic continuity is not established. Often these are anthropogenic overlaps (quarries, mines, road works or construction, etc.) which allow access to them. Vergari (1998) hypothesizes that "the genesis of underground karst can begin without flow, steady drowned." For us, it is obvious and an obligation. It seems that these morphogenetic stages are necessary for the establishment of the karst cave. The primokarst is also not the exploration field of speleologists, who will have to learn patience, just in case...

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