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DOLINES AND SINKHOLES: ASPECTS OF EVOLUTION AND PROBLEMS OF CLASSIFICATION

»DOLINE« IN »SINKHOLE« Z VIDIKA RAZVOJA IN TEŽAVE S KLASIFIKACIJO

UGO SAURO[1]

[1] Universitŕ degli studi di Padova, Dipartimento di Geografia, Via del Santo 26, 35123 Padova, Italia

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Ugo Sauro: Dolines and sinkholes: Aspects of evolution and problems of classification

The doline is the most representative landform of the karst surface. The name derives from the word dolina, a Slav term indicating any depression in the topographical surface. For nearly a century, this name acquired widespread use and a well defined meaning in the international literature; as a result it is not possible to substitute it with another term such as “vrtača” or “kraška dolina”, for example, as proposed by some authors (Gams, 1973, 1974). The use of sinkhole as a synonym for doline in the American literature has also created some ambiguity, because sinkhole is mostly applied in the sense of collapse doline or of cover doline. From the detailed studies of the dolines of different karst areas, it is possible to infer that the structure and the genesis of this form may be complex (Sauro, in press – a – and - b). The most correct way to define a doline is to add an adjective indicating a peculiar attribute. The most significant attributes are those linked to both the morphogenetical mechanism and the hydrological structure. On the basis of these attributes it is possible to distinguish several categories and types of dolines. Most importantly to understand a doline it is necessary to be able to reconstruct its history even if that may be complex, as some dolines formed by specific processes may later further evolve through different processes.
Key words: doline, karst landforms classification, karst morphodynamics.

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Ugo Sauro: »Doline« in »sinkhole« z vidika razvoja in težave s klasifikacijo

»Doline«, mednarodni izraz za vrtačo, je najbolj razširjena površinska oblika na krasu. Ime izhaja iz slovanske besede »dolina«, ki pomeni depresijo v topografskem površju. V skoraj 100 letih se je izraz razširil in danes ima v mednarodni literaturi dobro določen pomen. Zaradi tega ga ni mogoče zamenjati s kakim drugim izrazom, npr. »vrtača« ali "kraška dolina" kot predlagajo nekateri avtorji (Gams 1973, 1974). Uporaba izraza »sinkhole« kot sinonima za »doline« v ameriški literaturi vodi včasih do podvajanj, saj se izraz »sinkhole« uporablja predvsem za udorno ali pokrito vrtačo. Na podlagi podrobnega preučevanja vrtač na različnih kraških ozemljih je mogoče trditi, da je vrtača lahko tako po strukturi kot po nastanku, kompleksna oblika (Sauro in print, a in b). Vrtačo lahko najpravilneje opredelimo tako, da dodamo pridevnik, ki pojasnjuje posebnosti. Najpomembnejši pridevniki so tisti, ki so vezani tako na morfogenetske mehanizme kot na hidrološke posebnosti. Na podlagi teh pridevnikov je mogoče razlikovati več kategorij in tipov vrtač. Za razumevanje vrtače je najbolj pomembna rekonstrukcija njenega razvoja, pa četudi je ta kompleksen.
Ključne besede: vrtača, klasifikacija kraških oblik, kraška morfodinamika.

THE DOLINE: THE MOST REPRESENTATIVE KARST FORM

The morphological type called "dolina" (engl.: doline) in the international scientific literature is surely the most common, typical and representative landform of the karst landscapes.

In the monograph by Ford and Williams, this type is considered as the "diagnostic karst landform".

Prof. Gams devoted particular attention to this type of form (1973, 1974, 2000). Ivan Gams, in its "Slovene Karst Terminology", emphasises how the word "dolina" is commonly used in the Slav countries to cover a very wide meaning; to indicate any depression in the landscape, both open and closed hollows, like river valleys and karst poljes. For this reason, Gams suggests a more specific name for the karst dolina such as the Serbian word "vrtača", or the new unambiguous word "kraška dolina".

In the international scientific literature the terms "doline" and "sinkhole" are both utilised in a very wide sense to indicate medium-sized closed depressions, normally not holding water, in karst areas. Anyway, while the word "doline" is used mostly in Europe with a mainly "morphographic" significance, the term sinkhole is utilised mainly in North America with a predominantly "morphogenetic" meaning.

Now, it is not possible to substitute the term dolina (engl.: doline), that is already widely affirmed, with a new one.

The mental picture of the word doline is a subcircular bowl or funnel-like depression. That of "sinkhole" is a form which has originated through a gradual or sudden lowering of a portion of the topographical surface. In particular, in engineering geology, a sinkhole is a steep-side closed depression resulting from a sudden collapse downward of the hard rock or of the soft material on the surface. These two different ways of naming closed karst forms often cause ambiguity.

THE BASES FOR A CLASSIFICATION OF THE DOLINES

Probably the most correct way to define a form is to associate a term bearing a morphographical meaning such as "doline", with an adjective characterising a peculiar aspect of the "doline" in question.

It is possible to consider the dolines from different points of view for example:

1. the form referred to an object (bowl, funnel, pit), or to a geometrical shape (hemispheric, conical, cylindrical), or to the plan form (polygonal, star shaped, irregular, etc.),
2. the size (small, medium, large),
3. the genesis (by accelerated corrosion, by collapse, etc.),
4. the hydrological structure,
5. the functionality
6. the lithology and the tectonics

While the first two criteria are not significant to characterise the karst depressions and to distinguish them from other closed depressions in different geomorphological environments, the third criterion allows the distinction between the main categories of dolines (Fig. 1), and in particular:

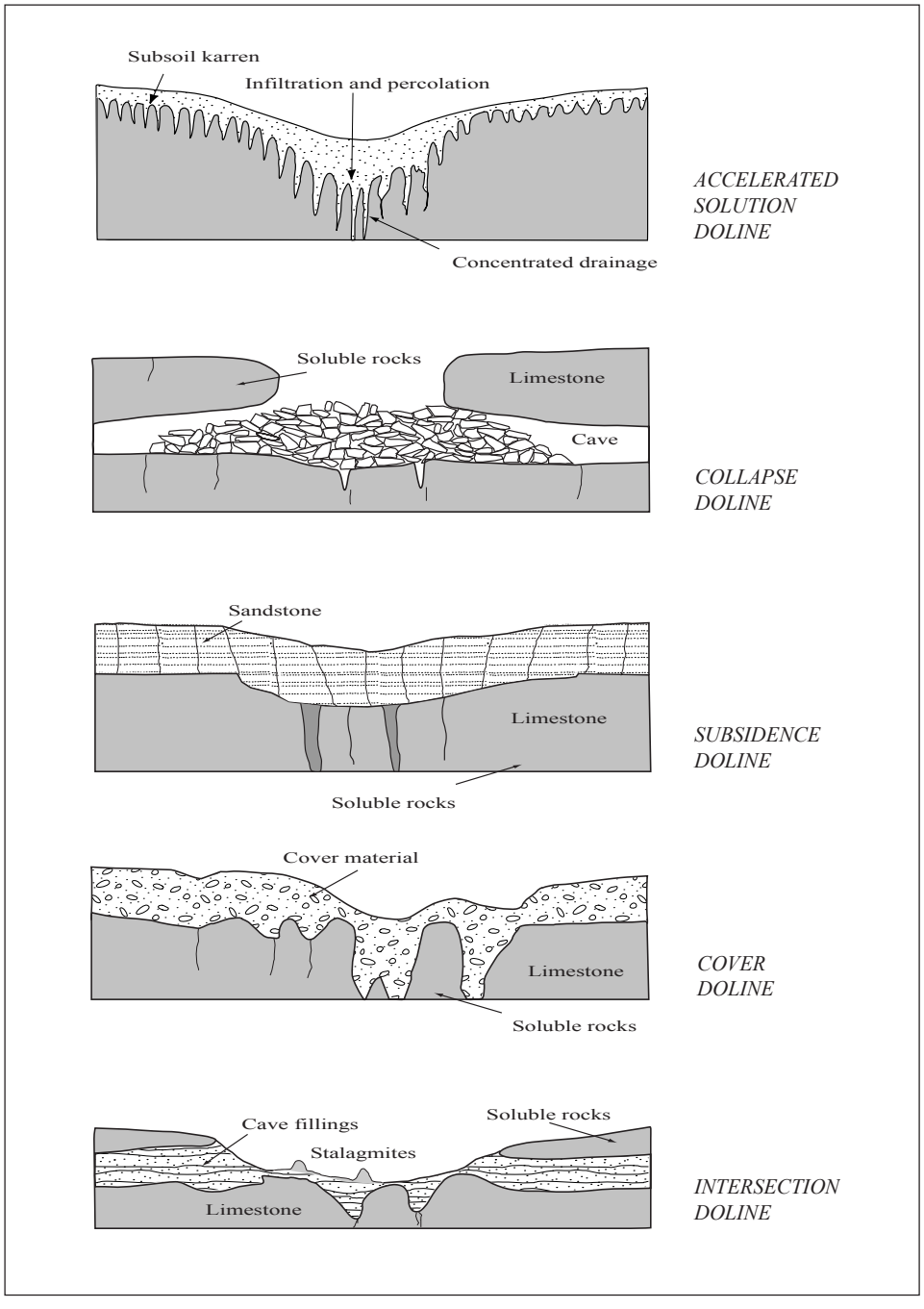

Fig. 1: The main categories of dolines. The anthropogenic dolines are not represented.

A - "normal", dolines, or "accelerated corrosion" dolines,
B - collapse dolines,
C - subsidence dolines,
D - cover dolines,
E - intersection dolines,
F - anthropogenic dolines.

Between the category of the normal solution dolines, the forth criterion provides the possibility of distinguishing some main types and in particular:

A1. drawdown doline,
A2. point recharge doline,
A3. inception doline,
A4. underprinting doline.

Between these types, it is possible to recognise sub-types according to points 5 and 6. For example, it is possible to distinguish very active dolines from inactive or relict dolines, "chalk type" dolines from "massive limestone type" dolines, fault line dolines from dolines developed along not displaced fractures, inception dolines determined by cherty lenses from inception dolines determined by the contact of different types of limestones, etc…

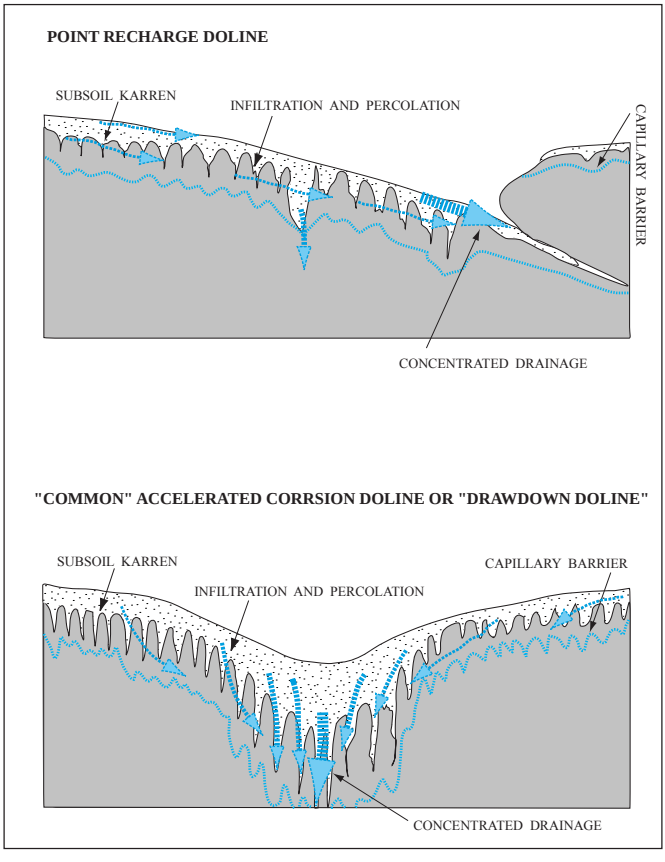

Fig. 2: The two most known types of accelerated corrosion dolines.

While types A1 and A2 are already well defined (Ford & Williams, 1989) and generally accepted (Fig. 2), the type A3 is a new one (Fig. 3), firstly described in the Encyclopedia of Caves, awaiting publication now (Sauro, in press - a). An "inception doline" results from the focusing of the vertical drainage of a hanging aquifer, hosted in a soluble rock and marked by a diffuse conductivity, through a vent in an impermeable layer situated

just below the bottom of the doline, or through a gap in a different rock formation lying below and showing a lower storage capacity. The concept of inception has been previously introduced for the speleogenesis phenomena (Lowe, 2000) and later utilised by some authors with slightly different meanings. An inception doline starts to form suddenly when the epikarst meets with a pre-existing peculiar structure (lithological and/or tectonic, but not simple fractures or bedding planes), able to focus the drainage and to determine a lowering by accelerated corrosion of the surface above, and, often, the speleogenesis of a vertical pipe below. So, the "inception" is an event in which the hydro-structural conditions of the epikarst suddenly change at a specific point, influenced by litho-structural factors. The root of the term inception is the latin word "incipere", which means "to begin", and this type of "normal" doline differs from the others because the forms are characterised by a starting of the hydrological and morphogenetical processes leading to the development of the form which is better defined in space and in time. Typical examples of inception dolines are those developing in the Monti Lessini (Venetian Prealps), just above the contact between the rock formations of Biancone (a chalk type limestone of the lower and middle Cretaceous) and of Rosso Ammonitico of the middle and upper Jurassic (a micritic, massive limestone, crossed by widely spaced fractures) (Fig. 4) (Sauro, 1973, 1974).

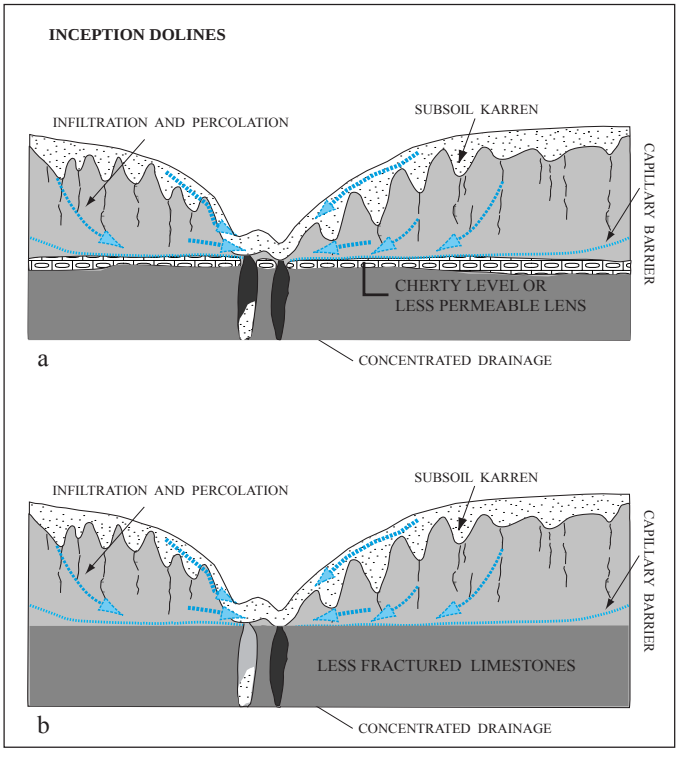

Fig. 3: The inception doline, a peculiar type of accelerated corrosion doline, sketched in two sub-types: a) drainage focused by a cherty lens, b) drainage focused according to a change of the lithology of the limestones.

An underprinting doline is a special type of normal doline, influenced by peculiar structures in the soluble rock found in its location and development, induced by the structure, topography and hydrogeological behaviour of an underlying insoluble buried rock, such as a weathered and fractured granite below a karstifiable rock. This type of doline has been described in a karst developed in the eolianitic rocks of Australia by Twidale and Bourne (2000). In this sense, also

the Cenotes of the area of Merida in Yucatan, disposed in correspondence to the outer ring of a deeply buried meteoric impact crater (structure of Chicxulub), could be considered as underprinting dolines.

The category of collapse dolines comprehends many forms which are different in type and size and originate from the collapse of the roof of a cave. Amongst these, there are the so called "karst windows", wide openings between the subterranean world and the outside environment.

The subsidence dolines are closed depressions which originate from the settling down of a surface area of an insoluble rock such as a sandstone, following the mass wasting by solution of an underlying soluble rock.

The cover dolines (also called "alluvial dolines") form as a consequence of the "absorption" of unconsolidated clastic sediments inside solution cavities which developed in an underlying soluble rock.

The intersection doline forms following the intersection of empty or filled caves by the topographical surface and evolves by the weathering and hydrological processes triggered by such an event. Seen from the prospective of a speleologist, these forms may be called "unroofed caves", or "roofless caves" (Mihevc, 2001).

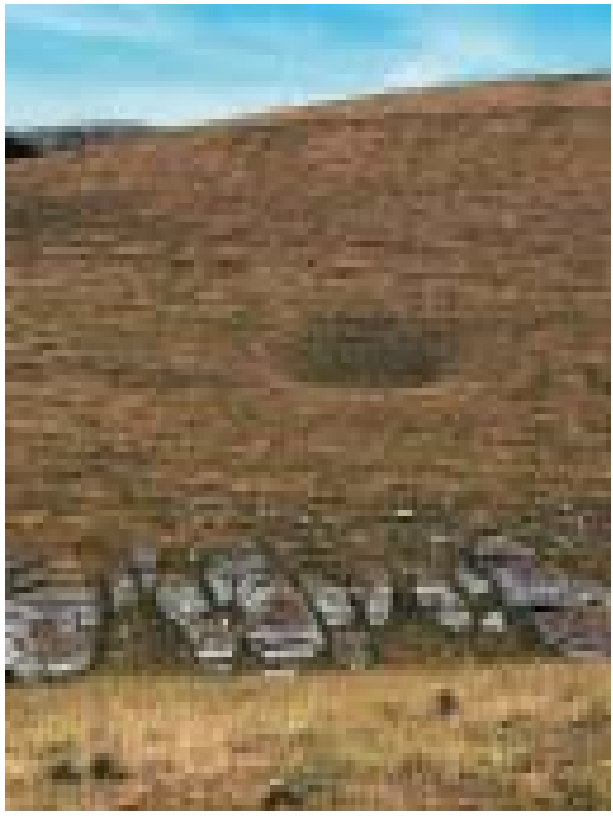

Fig. 4: A typical inception doline developing just above the contact between the rock units Biancone and Rosso Ammonitico (below) in the Monti Lessini (Venetian Prealps, Italy).

Fig. 5: Craters of bombs of the first World War partly evolving as dolines. These craters represent peculiar types of anthropogenic dolines.

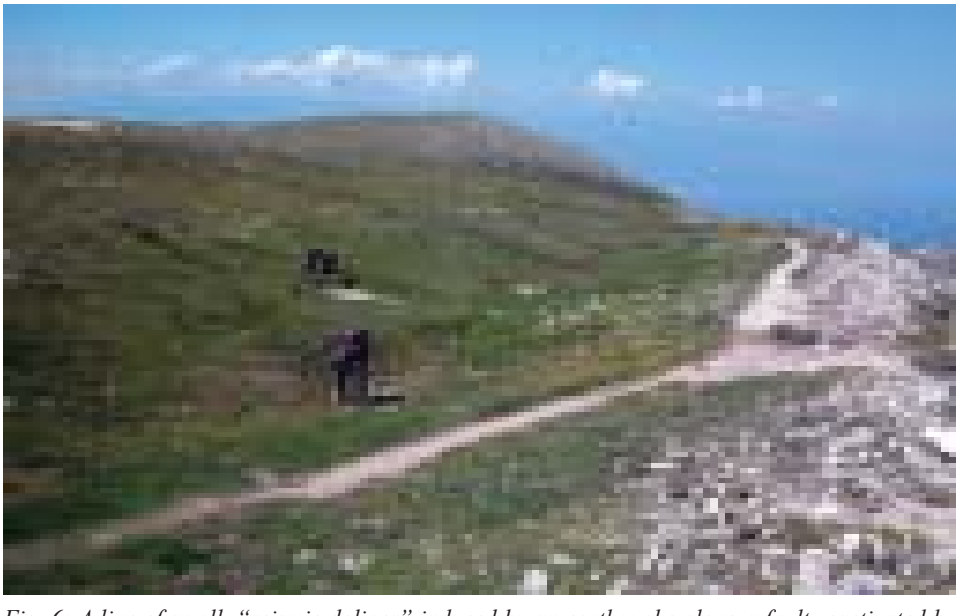

Fig. 6: A line of small, "seismic dolines" induced by an earthquake along a fault reactivated by the seismic shook. The topographical surface is faulted. The dolines are near the Duca degli Abruzzi mountain hut in the Gran Sasso Mountain Group (Gran Sasso d'Italia).

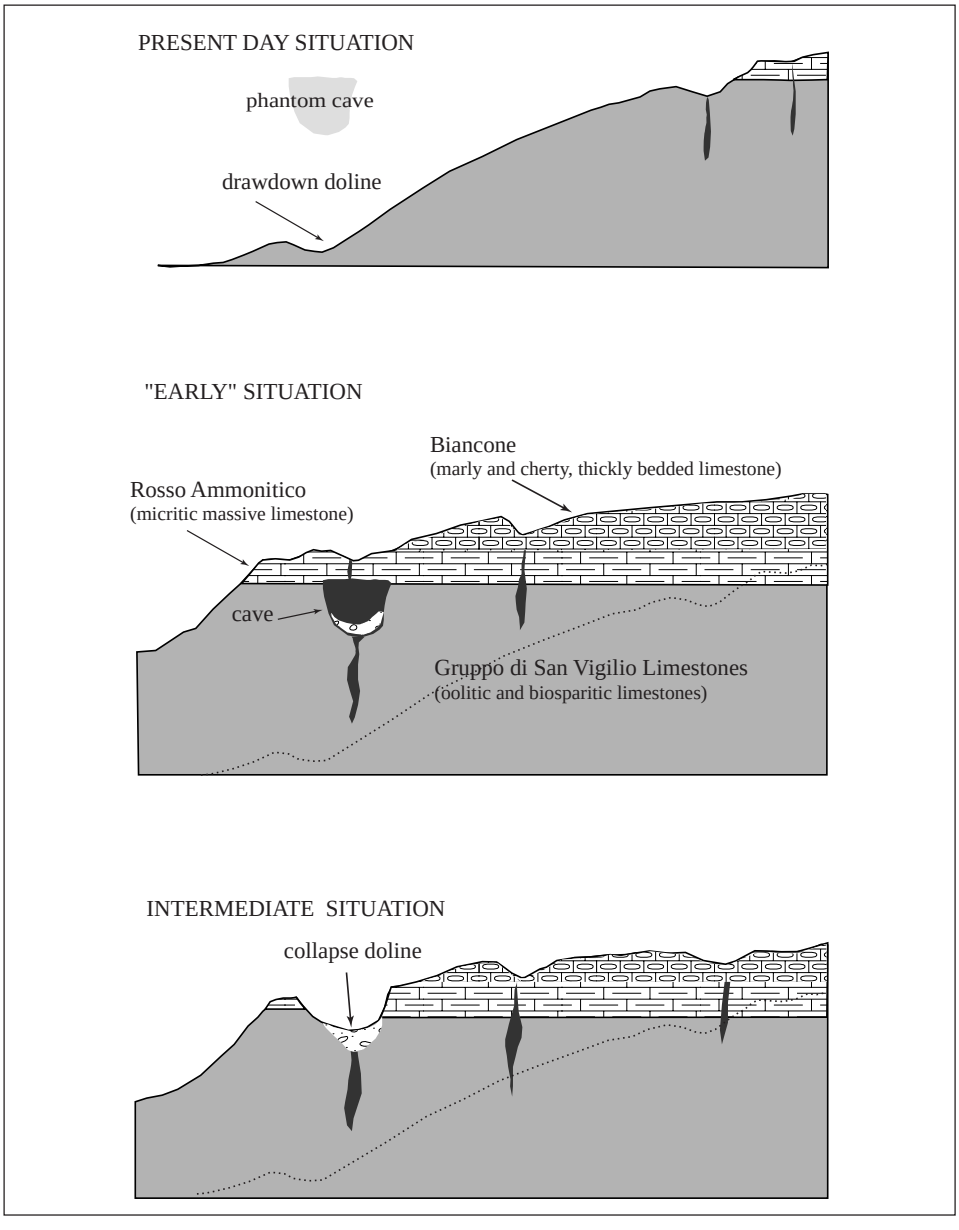

Fig. 7: Model of evolution of an isolated drawdown doline in the Monti Lessini (Venetian Prealps), near Bosco Chiesanuova. According with the model this doline originated firstly as a collapse doline and after evolved as a drawdown doline. The model explains the presence of this doline in its peculiar morphotectonic settings. A problem is how to classify such a doline which is a special inherited form starting from a different lithological and evolutionary settings.

Criterion six allows us to distinguish the dolines on the basis of the lithology. So it is possible to speak of salt dolines, gypsum dolines, limestone dolines, dolostone dolines, lithological contact dolines (for example some dolines developed at the contact point between a limestone and a not soluble rock, such as a basalt). In some peculiar geological and climatic environments it is also possible to find dolines in very low soluble rocks, such as quarzitic sandstones. In the Guiana shield of the Orinoco basin (Venzuela), quarzitic sandstone-dolines exist, which mostly originated from the collapse phenomena of caves which developed over a very long time span (tens of millions of years) in the same rock.

The table shows the most common types of dolines which develop in different groups of rocks:

LIMESTONES	
most common	also present
DRAWDOWN	POINT RECHARGE
COLLAPSE	INCEPTION
	INTERSECTION
GYPSUM AND SALT	
most common	also present
POINT RECHARGE	DRAWDOWN
	COLLAPSE
	INCEPTION
	INTERSECTION

The dolines may be also distinguished on the basis of the climatic environment where they form. So, there are the tropical dolines with a star or polygonal plan shape and the middle latitude dolines mostly with a circular plan shape. Peculiar types of dolines are the cenotes, or "water table dolines" which are typical of some tropical areas, and the blue holes or "submarine" dolines.

If the distinction is based on the closed shape and/or on the functionality of the form, some anthropic and anthropogenic forms may also be considered as dolines. Worth noting amongst these, are the bomb craters and some quarries. In the Venetian Prealps more than 50% of the First World War bomb craters in some areas now behave like true drawdown dolines (Fig. 5), also because of the strongly fractured rock (Celi, 1991). Some old quarries are now also evolving as dolines. Between the anthropogenic dolines many cover dolines are triggered both by the lowering of the water table connected with the exploitation of the karst aquifers and by mining activities.

A relatively uncommon category of dolines is represented by the "seismic dolines". Along some faults activated during recent earthquakes, it is possible to observe funnel like "dolines", originating as a result of seismic movements, which when they develop in soluble rocks, evolve later as true karst dolines. Some of the dolines in the mountains of the Abruzzo (Central Italy) could have started or have been triggered by "seismic shocks" (a line of small dolines of this type is visible near the mountain hut Duca degli Abruzzi in the Gran Sasso Mountain Group: Fig. 6).

CONCLUSIVE REMARKS ON THE PROBLEMS OF NOMENCLATURE

If there are so many criteria in the definition of a doline, it is a problem to establish what is the priority or most correct way to define the form.

If we decided to consider all the criteria, we should prepare a special data base, to be compiled as an "identity card" for each doline. We should insert not only the morphometrical data into this data base, but also the "structure" of the complex landform (included the buried part), the category, the type, the hosting rock, the climatic environment, etc. But, this operation, even if complex and not always easily carried out, sometimes results as inadequate to fully understand the landform.

The following example helps to understand some of the problems in providing the definition of a doline.

In the Monti Lessini (Venetian Prealps), near Bosco Chiesanuova, inside a mostly fluviokarstic relief there is a medium sized doline. The doline is just uphill of Contrada Gherte, inside a slope made up of oolitic and biosparitic limestones of the formation "Gruppo di San Vigilio Limestones", where it is difficult to find dolines, except just below the lithological contact between the Rosso Ammonitico (the rock formation above) and the Gruppo di San Vigilio Limestones. Normally, the dolines present just below the lithological contact evolved from collapse dolines which developed in the Rosso Ammonitico itself by the breakdown of the roof of a cave. This type of cave forms below the Rosso Ammonitico or, secondarily, in connection with inception dolines which develops just above the Rosso Ammonitico, in the lower Biancone.

So, on the basis of the evolution models for the karst features in the high Monti Lessini, verified by many geomorphological settings (Sauro, 1973, 1974), this doline, probably, started to evolve as a collapse doline, and continues to survive, even if the initial conditions have changed ((Fig. 7). Now the doline is functioning as a drawdown doline, but in its earlier life it was a collapse doline.

Which, therefore, is the best name to give it? Is it more important to consider the present day hydro-structural condition or the way it originated? The beginning probably occurred a very long time ago (probably during pre-Quaternary times, if we consider the thickness of rock wasted away as the result of the chemical denudation after the collapsing of the cave roof formed of Rosso Ammonitico).

In this case, I believe that it is more correct to consider the present day situation, but, anyway, without the formulation of an evolutionary model it is also difficult to understand such a form.

This example helps us understand how complex the history of a doline can be and how problematic the definition of a form with a simple attribute may be, alongside the name. As always nature is much more complex than our schemes and models, and the karst environment represents a very good benchmark to try to improve our understanding.

** NOTE*

Research carried out inside the following research programs: 60% - 2002 and 2003: Geosistemi carsici italiani e del Mediterraneo: dinamica, risorse e storia evolutiva.

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