HIGHLIGHTS ON DOLINE EVOLUTION

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ABSTRACT

The dolines are originated by accelerated corrosion in connection not only with surface overland flow but also with the evolution of gradients of hydraulic conductivity inside a shallow limestone "zone," called "epikarst".

If the hydrological model based on the focusing of solution process is clear, it does not explain all the aspects of doline evolution.

In fact a lot of questions emerge from the field analysis of the dolines. For example we may see that very small dolines are lacking in most of the doline populations and that often dolines begin to develop very near to the contacts between a caprock and a limestone rock unit or between a marly limestone rock unit and a pure limestone rock unit.

The interference between fluvial, slope, glacial and periglacial processes may interfere with doline evolution.

To solve the morphogenetical problems of dolines we must consider, not only the surface form, or "epiform", but all the doline structure from the epykarst to the interface soluble rock - filling deposits, to the soil cover.

It is possible to verify that in the first stages dolines often evolve as "cryptoforms", before to become epiforms. After they have become epiforms they act as traps for sediments both local and allogenic. So their evolution and history may be very different according to structural control, hydrological and environmental characters and changes.

RIASSUNTO

Le doline sono originate dalla corrosione accelerata in relazione non soltanto con il ruscellamento superficiale ma anche con l'evoluzione di gradienti di conduttivitê idraulica all'interno dalla zona carsificata piu superficiale, datta "epicarso"..

Tuttavia, anche se il modello idrologico sulla focalizzazione dei processi di soluzione puo dirsi soddisfacente, esso non basta a spiegare tutti gli aspetti dell'evoluzione delle doline.

Dalla ricerca sul terreno emergono molti problemi.

Tra l'altro noi constata che nella maggior parte delle popolazioni di doline mancano le forme di piccole dimensioni e che spesso le doline si sviluppano in prossimitê del contatto fra formazioni con caratteri diversi ed in particolare fra "caprocks" e calcari o fra calcari marnosi e calcari puri.

Con l'evoluzione delle doline possono intereferire anche processi fluviali, di versante, glaciali e periglaciali.

Per risolvere i problemi dell'evoluzione morfologica delle doline occorre considerare, oltre alle condizioni ambientali, non soltanto la forma superficiale, ma l'intera struttura della dolina dall'epicarso, alle interfaccie fra la roccia solubile e i depositi di riempimento ed il suolo.

E' possibile verificare chè negli stadi iniziali la dolina spesso si evolve come una "cryptoforma", prima di divenire una "epiforma". Dopo essere divenuta una epiforma essa agisce come una trappola per i sedimenti sia locali, sia allogenici. La storia evolutiva puij essere molto diversa in relazione all'influenza della struttura ed ai caratteri ed ai cambiamenti idrologici ed ambientali.

THE SOLUTION DOLINES

The doline is the most specific surface form of karst landscapes. The more common type of doline is the solutional one, which is an elementary hydrographic unit, comparable with a valley of the fluvial landscape.

Analogously with the valleys the dolines present a large variety of typologies in spite of the seeming dullness of the forms, as a wide range in size (from a few meters to about one kilometre in diameter and from a few decimeters to more than 100 meters in depth), and a great diversity of shapes.

Even if tens of Authors have written about dolines, the evolutionary aspects of these forms need supplementary research.

After GAMS (1974) dolines are originated by accelerated corrosion; WILLIAMS (1985) has illustrated a hydrological model of doline evolution, based on the development, by solutional processes, of gradients of hydraulic conductivity inside a shallow limestone "zone," called "epikarst," just below the soil surface.

These two alternative models may fit together, but they don't explain some peculiarities of these forms as, for example, why only very few small forms, interpretable as embryonic stages (dolines of few meters in diameter and few decimeters in depth) are recognizable on the field; and why there is a so large variability in doline characters.

From now on, some outstanding questions follow population of dolines:

1) Why very small dolines (a few meters in diameter) are lacking in most of the populations dolines?

2) Why some populations of dolines begin to develop very near to the lithological (both stratigraphical or tectonic) contacts between a caprock and a limestone rock unit or between a marly limestone rock unit and a pure limestone rock unit?

3) Why and how some fluvial valley bottoms begun to evolve as chains of dolines?

4) Why and how some large forms, as the glacio-karstic depressions, are of complex origin?

5) How dolines act as traps of sediments and what are the main consequences of the sedimentary fillings?

If we could answer to these questions we will probably solve the main problems that arise from the geomorphological studies on the field.

THE PUZZLE OF LACKING OF SMALL DOLINES

Most of the doline populations are lacking of small forms, less than 10-15 m in diameter. In fact it is impossible to found them on large scale maps, on aerial photographs and directly on the field (*Fig. 1*).

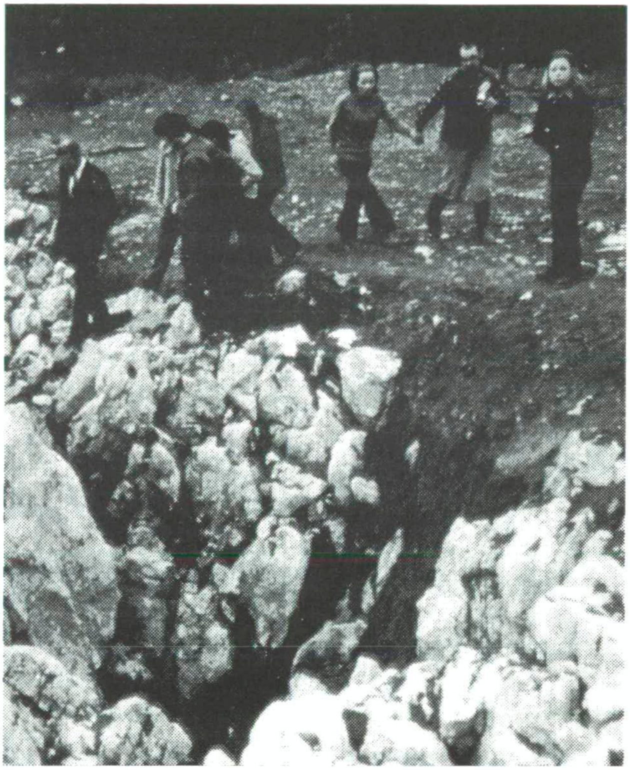


Figure 1 *Cryptodoline cleared by soil fillings in a quarry near Vrhnika (Slovenia). Near the forms is recognizable Prof. Ivan Gams* (photograph taken by Sauro in 1974).

This is curious if one thinks that medium size dolines should have developed from smaller forms and that consequently a nearly continuous series of forms should exist. Good examples of this situation are the Classical Karst of Trieste and the karst in conglomerate rocks in Montello (Venetian Fore-Alp, Italy).

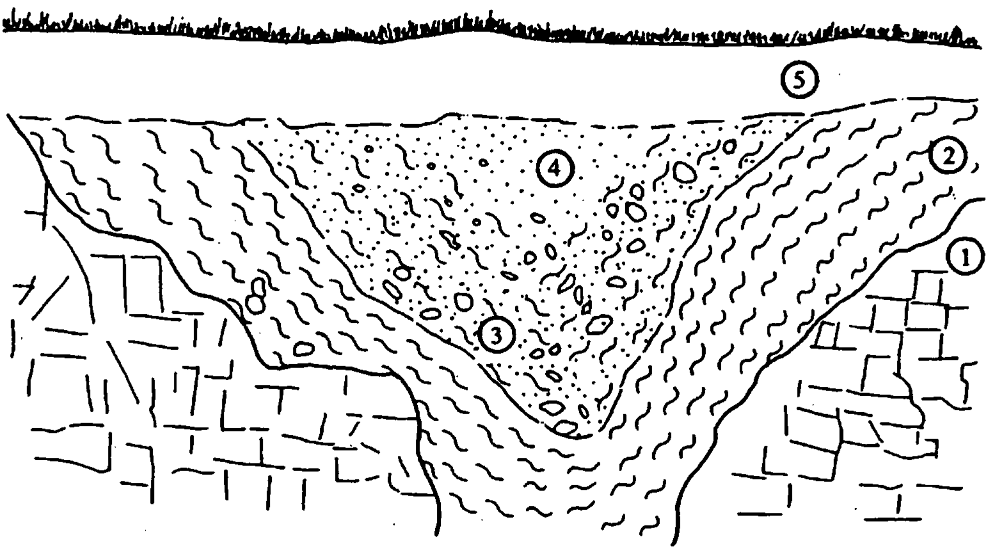
The only small doline-like forms exist:

- as fissure like, or subcylindrical hollows;
- on loose deposits because of suffusion or sediments "subsidence";
- as field of small conical dolines in halite karst and in some gypsum karst;
- as funnel shaped depressions along some active faults with evidence of surface faulting;
- as craters resulting from bombs.

If one goes to see the artificial cuttings in the quarries or along new routes it is possible to observe that the smaller karst depressions are filled by debris and soil sediments. Many dolines become to exist as "cryptokarstic structures" before to become surface forms. The first Author who has underlined the importance of cryptokarst is NICOD (1975).

THE CONTACT DOLINES

The influence of the lithology and of the geologic structure on doline evolution is clear where there is a stratigraphic or tectonic transition between dissimilar permeable rocks with different hydraulic behaviour. It is well known that dolines and shafts often develops near the contact between a caprock and a karstifiable rock unit (*Fig. 2*). Field of dolines of this type are well known in Mammuth Cave National Park (Kentucky, USA).



1=bedrock constituted by a marly limestone, 2=mostly clay "terra rossa" paleosol, 3=silty "terra rossa" paleosol, 4=loess like silt, 5=active soil

Figure 2 *Section of a cryptodoline in an artificial cutting in the Lessini Mountain (Venetian Fore-Alps).*

Very interesting examples are in the Lessini Mountains (Venetian Fore-Alps, Italy), where most of the dolines are to be found near the stratigraphic or tectonic transition between of whitish marly limestone closely stratified and densely fractured ("Biancone" of Lower and middle Cretaceous) and a more pure and massive limestone with less dense and more extensive fractures ("Rosso Ammonitico" and "Calcari Oolitici" rock units of Jurassic Period). Here the dolines occupy well defined morpho-structural positions (SAURO, 1973, 1974) as:

- Infacing slope dolines and shafts;
- "Rosso Ammonitico" structural surface dolines and shafts;
- Fault-line dolines and shafts;
- Valley bottom dolines in the lower Biancone.

Doline evolution seems linked with the downward transition from a subhorizontal circulation (aquifer levels in a small lithoclastic network) to an essentially vertical one (diaclastic circulation) from the marly and more fractured limestone to the underlying and/or adjacent more pure and fewer fractured limestones.

In the erosional transition between the two types of rock units doline morphogenesis is preceded by the development of peculiar epikarstic structures controlled by the lithological and structural transition.From the hydrological point of view these dolines represent an intermediate situation between the "point recharge dolines" and the "drawdown dolines" of FORD & WILLIAMS (1989).

CHAINS OF DOLINES THAT MARK THE DEATH OF A FLUVIAL VALLEY

The more common example of interrelation between karst and non karstic processes in dolines evolution is to be found where doline evolution follows a phase of fluvial morphogenesis.

In the evaporitic karst in west Sicily (Southern Italy) a valley pattern developed in the impermeable covers has been inherited by a soluble gypsum rock unit (AGNESI & alii, 1989). Here dolines development occurs on the valley bottoms, beginning from the earliest swallow which acts as "point recharge hollow." Each valley becomes a blind fluvial-karstic closed depression. In the time new and more active swallow-holes develop upstream. So chains of "point recharge" dolines are recognizable with their bottoms upstream at a progressively lower altitude. These forms are also common in limestone (good examples are to be found in the Bucham karst, Victoria, Australia).

If a network of fluvial valleys, cut in a not karstic rock unit, begins to dissect karstic rocks, karst processes cause a loss of water on the valley bottoms till to a complete "drying" of the surface streams. The dried valley pattern inherited by the karst rocks continues to evolve because of the chemical solution of the valley bottoms, accelerated in comparison with the slopes and the ridges. If dispersed infiltration and large debris accumulation occurs, as in some dry valleys of the Venetian Fore - Alps, very few dolines develop. These forms evolve especially where concentrated water percolation occurs (*Fig. 3*).

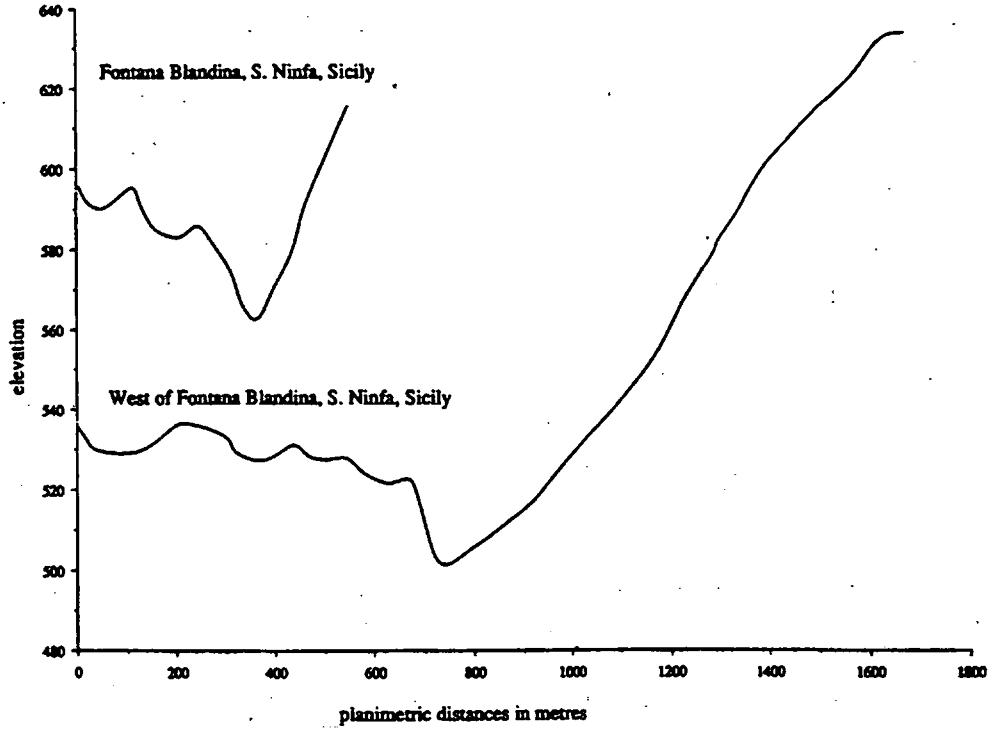


Figure 3 *Profiles of chains of "point recharge dolines" formed along valleys in the evaporite karst of Santa Ninfa in western Sicily. The bottoms upstream are at a progressively lower altitude. The vertical exaggeration is of 7,7.*

OTHERS MIXED, POLYGENETIC AND POLYPHASIC ORIGIN CLOSED DEPRESSIONS

The chains of closed depressions along the bottom of a previous fluvial valley are of mixed origin: fluvial and karstic.

In mountain environment it is possible to find other types of depressions of mixed origin. The more typical are the glacio-karstic depressions formed by an alternation of glacial and karstic processes. Some of these depressions are on the bottom of a glacial cirque, others on plateau surfaces are developing in their upper parts as small glacial cirques. Apparently sometimes glacial cirques have preceded dolines, in others dolines have preceded glacial cirques.

DOLINES AS TRAPS

In the middle latitude karst, doline evolution is linked, beside with the karst denudation, with others weathering processes working on the slopes and with fillings deposition inside the closed depressions by soil sediments, periglacial scree deposits, loess like deposits, and sometimes by glacial deposits and by volcanic ashes. In many areas fillings from a few meters till to some tens of meters have been recognized (MAGALDI & SAURO, 1982, ZAMBO, 1985).

In Monte Baldo (Venetian Fore-Alps) a large variety of dolines are present:

- dolines with flat, horizontal and very large floors; with a marked difference between minimum and maximum depths (difference between the highest and lowest points the perimeter with respect to the floor of the depression);

- dolines with small "terraces" in their interiors, with respect to which one or more funnel shaped depressions are placed;

- "open dolines" with a flat horizontal floor not completely surrounded by slopes (here minimum depth is zero and the doline is recognizable by the half amphitheatre shape of the slopes);

- "opened dolines" with no flat horizontal floor, consisting of bowl shaped depressions with one side dissected by a small valley.

Sometimes the filling deposits have nearly completely obliterated an older karst relief, consisting in large depressions, and favoured the development of clusters of smaller depressions inside the ranges of the old ones. Many more recent smaller dolines are found grouped inside the relicts of these "paleo-forms".

The filling deposits of the higher area are mainly composed of rather angular limestone fragments varying in their diameters from a few centimetres to some decimeters and embedded in yellowish silt.

The current karstic forms are masked by deposits that have filled the original dolines sometimes to the rim.

If we search to reconstruct the landscape evolution we may suppose the alternation of three main types of morphogenetic phases, occurred in different environmental conditions:

- in a warm and humid climatic phase, evolution of a karstic relief composed of more and less cone-shaped hills with large, deep dolines (now mostly dismantled and generally hard to distinguish);

- in periglacial conditions relief dismantling and filling of the karst depressions by aeolic loess and by angular fragments produced by cryoclastic dismantling of the ridges between the dolines;

- in temperate and humid conditions, which may be referred to interglacial periods, intense karstic morphogenesis.

Some very interesting examples of doline evolution are to be found also in the Velebit Mountains, where at least two different models are distinguishable.

In the central plateau very large, deep funnel shape dolines exist, nearly without slope covers and filling deposits inside. In the southern Velebit the dolines are much more similar to those of M. Baldo.

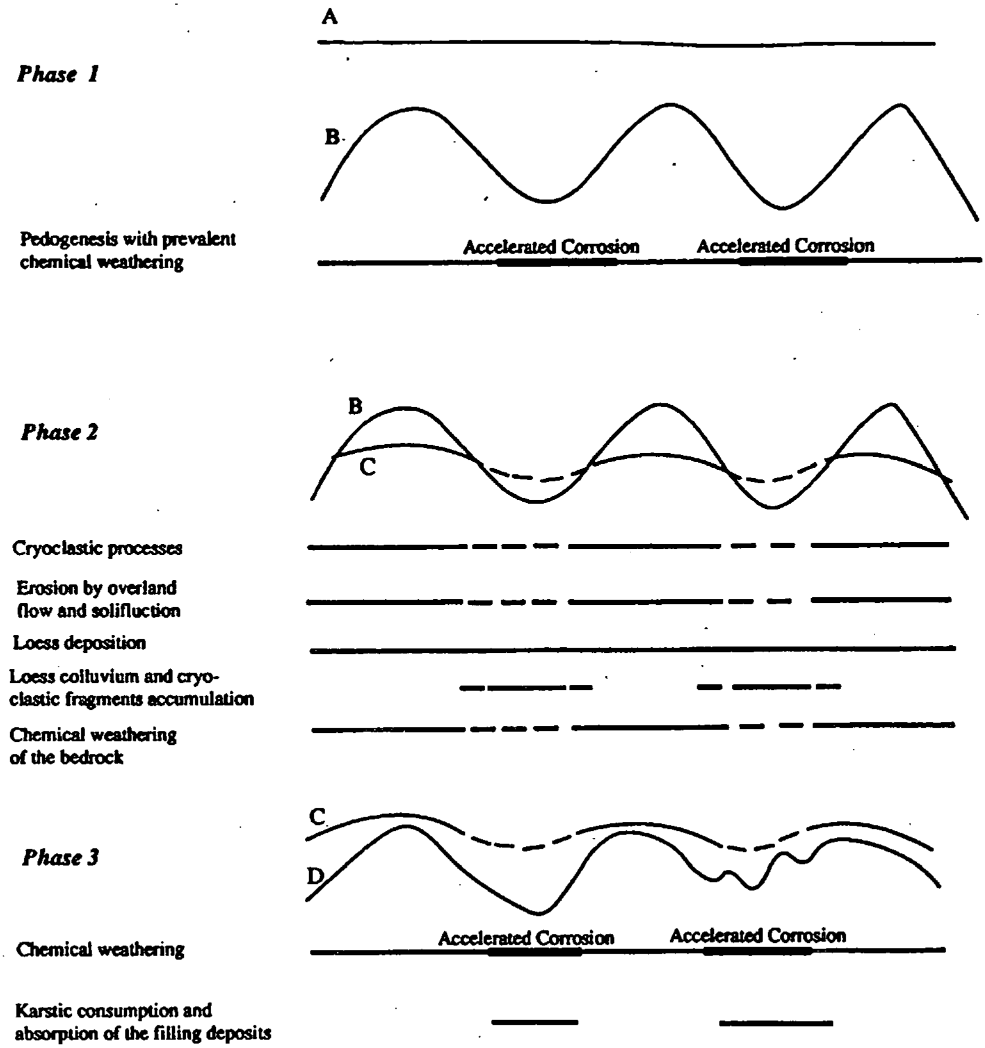


Figure 4 *Diagram illustrating the sequence of different phases of doline relief evolution in Southern Monte Baldo plateau* (Venetian Fore-Alps, Italy) *and the role of different erosional and depositional processes.*
After an initial phase of karstic morphogenesis on limestone without detritic cover, alternate phases occurred, with dismantling of karstic relief in periglacial conditions (type 2), and karstic erosion on an originally complex relief in temperate and humid climatic conditions during the Interglacials. The letters, A, B, C, D, make reference to the morphological profiles (profiles on the bedrock = continuous lines; profiles on deposits = dashed lines) (from MAGALDI & SAURO, 1982).

The only difference between the two populations is represented by the lithology. In particular the large dolines of central Velebit are developed in a massive limestone breccia unit, that shows a very low sensitivity to cryoclastic weathering. During the last glaciation these dolines have acted as traps of wind transported snow, and have determined the formation of a plateau glacier, "radicated" inside the dolines and very thin outside these forms. In fact after the "Bora" wind had filled with snow the hollows, no more traps exist and so the snow was taken away from the flat surface of the plateau. In the southern Velebit the limestone is much more sensible to frost shattering and so most of the dolines have been partly dismantled by periglacial processes and partly filled by cryoclastic fragments and loess like deposits. On some slopes selective weathering has brought in relief the breccia filling some dolines, which is less sensitive to cryoclastic dismantling than the outside limestone.

Figure 5 *A partially filled doline and some completely filled "open dolines" with a flat horizontal floor not completely surrounded by slopes* (Monte Baldo).
The filling deposits are composed of rather angular limestone fragments embedded in yellowish silt.

So in these cases the main factor of the distinct landform evolution is represented by the different lithological characters of the limestone rock units.

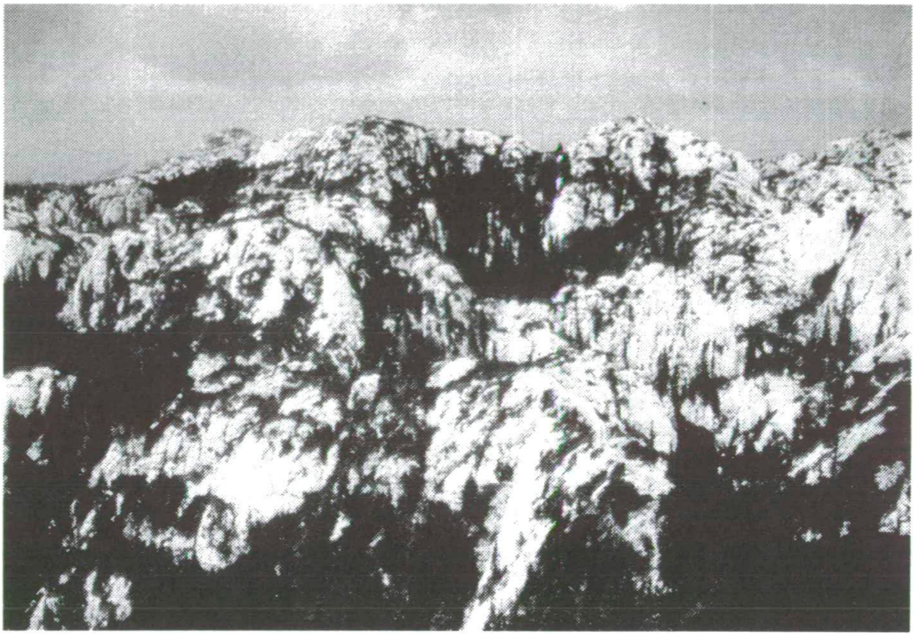


Figure 6 *The very large, deep, funnel shape dolines in the central Velebit (Hrvatska), developed in a massive limestone breccia unit that shows a very low sensitivity to cryoclastic weathering*. During the last glaciation these dolines have acted as traps of wind transported snow, and have determined the formation of a plateau glacier, "radicated" inside the dolines and very thin outside of these forms.

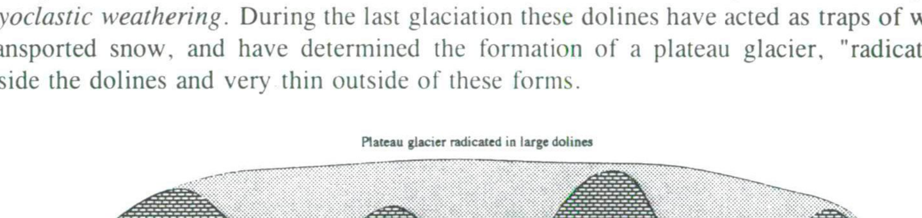


Figure 7 *Sketch profile of the plateau glacier radicated in the large dolines which should have existed during the last glaciation in the central Velebit plateau (Hrvatska).*

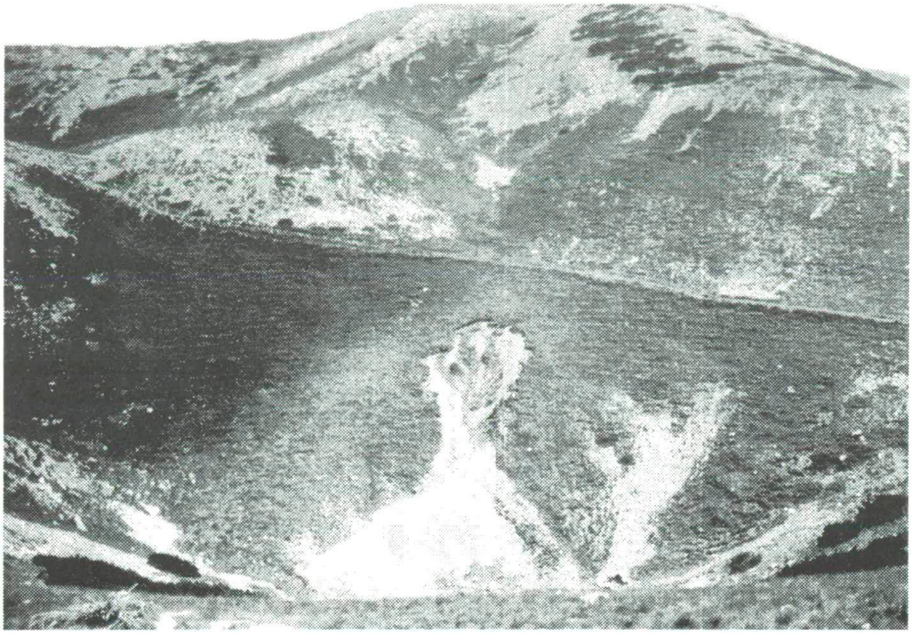


Figure 8 *Doline in the southern Velebit (Hrvatska), similar to those of M. Baldo. Inside the dolines a karstic consumption and absorption of the filling deposits in now occurring.*

An other interesting example is that of the "low relief cockpit karst" of Alte Murge (Puglia, Italy) where the karst hollows have been partially filled by volcanic ashes, in successive stages (SAURO, 1991). The filling deposits have favoured the development of an embryonic hydrographic network constituted by flat or rounded valley floors. In periglacial environment valley patterns have also developed on "inclined" plateau surfaces overlying a former doline relief.

SOME FINAL REMARKS ON DOLINE EVOLUTION

Dolines are not only topographical forms but also hydrological, lithological and sedimentological structures resulting from the presence inside the depressions, cut in soluble rocks, of fillings of different sediments with peculiar geometrical and sedimentological characters.

So if we want to understand the evolution of dolines we must consider:

- the lithological and tectonic control;
- the interrelations between karst and non karstic processes;
- the characters and influence of fillings.

In fact in doline evolution we assist to interchanges and mutations as:

1) from hydrological structures to cryptoforms;

2) from cryptoforms to epiforms;

3) shape and structure modifications by interference between karstic, slope, fluvial, periglacial and glacial processes.

The first stage of doline evolution is certainly explained by the role of the "epikarstic zone." In the sense of WILLIAMS (1985) the "epikarstic zone" is the upper part of the karstified rock volume, with a larger and more diffused secondary porosity by growth of karst voids.

Normally there is not a direct contact between the epikarst rock surface and the atmosphere, but a filter formed by the "loose covers," made by soil, soil sediments and a mixture of soil sediments, allogenic sediments (volcanic, eolian ...), insoluble residuals, and rocky fragments.

We will call this "filter body" "epicover.

"The "epicover" above the "epikarst" may be also interested by karstification when it contains rocky fragments or carbonate residuals.

The development of "cryptoforms" and the transformation from "cryptoforms" to "epiforms" may be explained by three main aspects:

- the character of "epicover" (three dimension geometry, permeability, water capability, percent and surface of soluble fragments, etc.);

- the processes at the "interface" between the "epicover" and the "epikarst";

- the characters and hydrological behaviour of the epikarst.

All these aspects are linked with the environmental processes of the outer surface and with the control of the topography, lithology and tectonic.

The three dimensions structures of the epicover are characterized by a net of wedges and, at the crossing of the meshes, by cones and cylinders.

Inside this structure an "epicover aquifer" exists, strictly interconnected with the "epikarstic aquifer. The two aquifers could be called "epiaquifers".

When in correspondence with a "cone" or a cryptodoline an epidoline develops, slope processes play a role inside the basin and mass transfer from the upper part of the form to the lower one occurs.

Carbonate soluble fragments, detached by weathering, are carried by slope processes from the sides of the doline to the bottom. Therefore, the weathering of the slopes causes an enlargement of the depression, a reduction of the steepness of the slopes, an abating of the depth and an increasing of the average diameter/depth ratio; beside this most of the rock surface, which may become in contact with the water solutions, is no more on the slopes but inside the filling deposits. So a large part of the solution capability is used inside this clastic, partly soluble body.

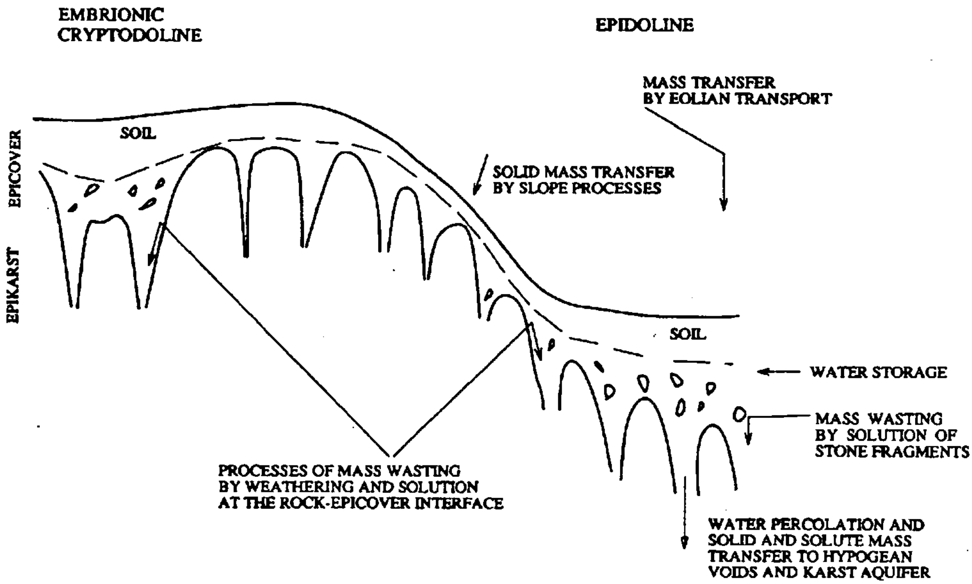


Figure 9 *Sketch profile of structures and processes occurring inside cryptodolines and epidolines.*

In the karst of middle latitudes, if the sensitivity to frost shattering of the soluble rocks is high, the bottom deposits may become very thick (also more than 10 m thick) and may preserve from the cryoclastic weathering the buried part of the slopes that may remain steeper than the upper exposed part.

A very important factor is also the mass trapping inside the basin of allogenic materials as loess, volcanic ashes, etc.

Examples of filling deposits of dolines in different karst areas of the world show how complex may be the history of these forms and how the deposits trapped inside the closed depressions may contain very important information about landscape evolution and environmental changes.

Further research work is necessary devoted not only to the surface forms but to the entire structure of dolines.

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